OCTOBER 1958

THE WELDING JOURNAL

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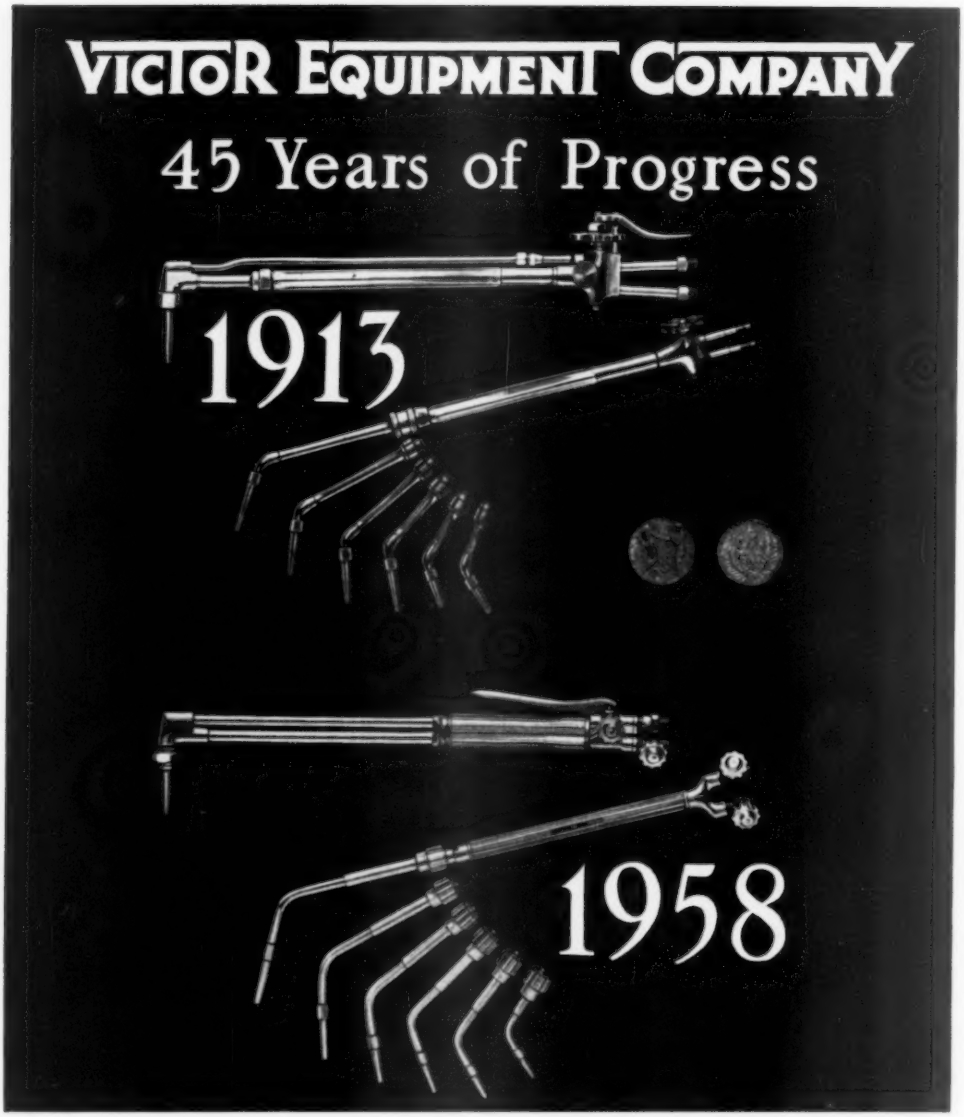

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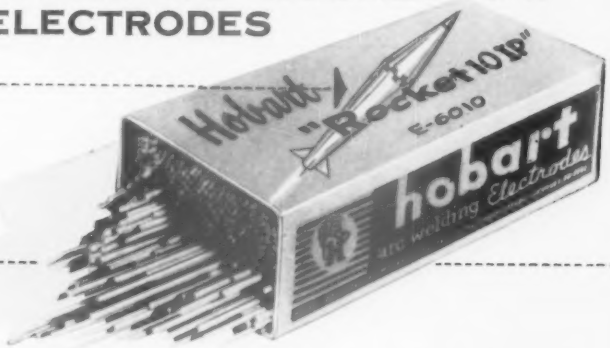

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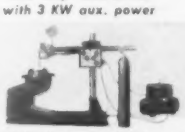
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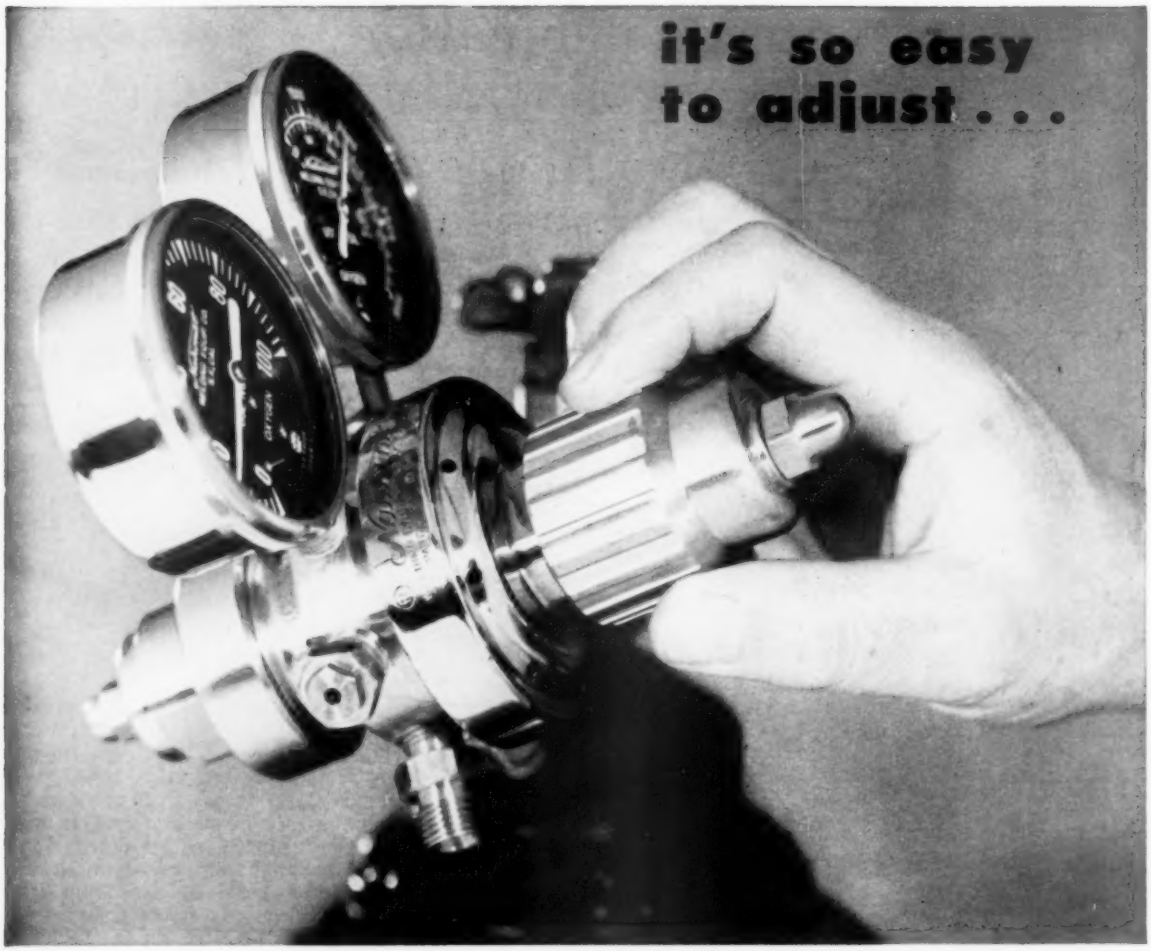

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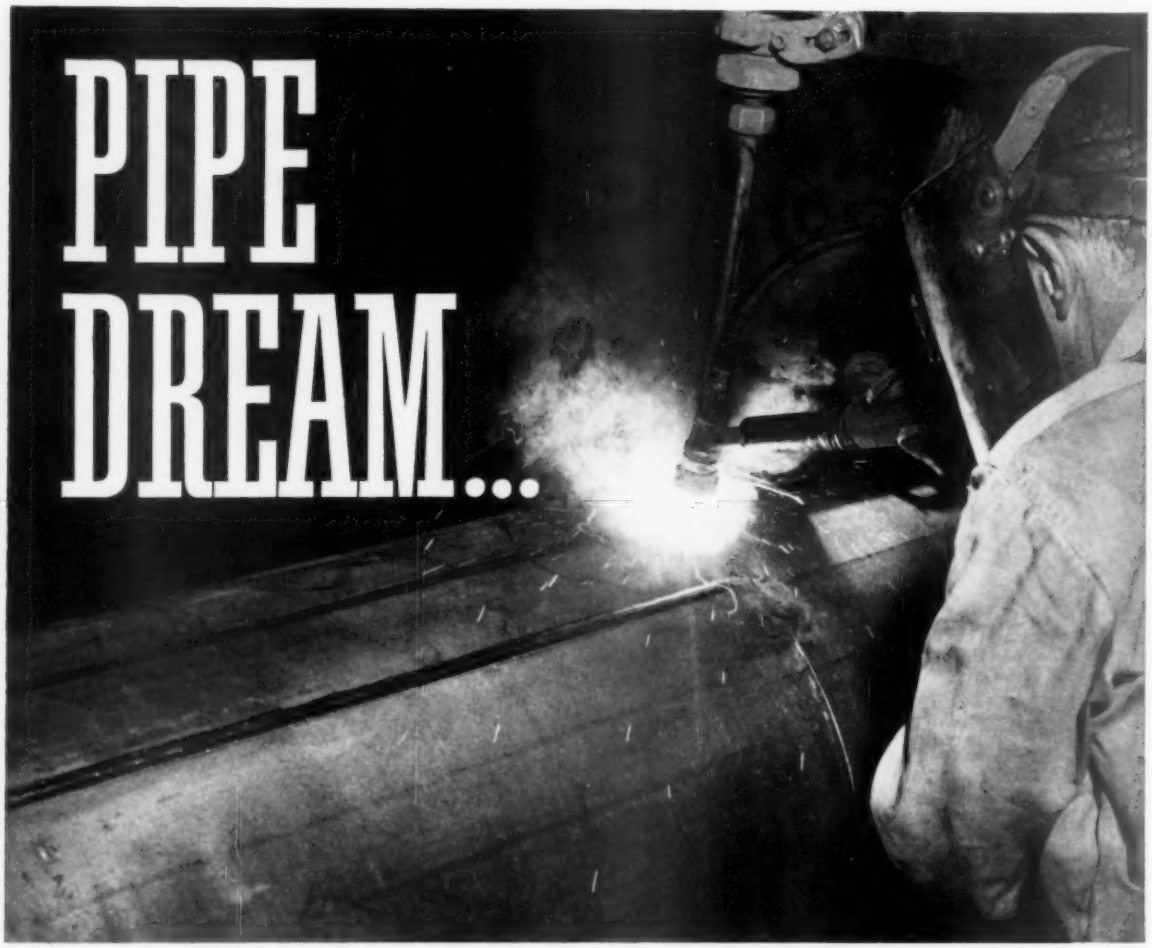

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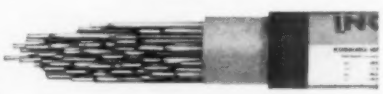

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ATOMIC ENERGY COMPONENTS AND WELDING REQUIREMENTS

In the short period of eight years or so, during which atomic-energy components have been built for full-scale atomic-energy plants, the welding specialist has been required to learn many new lessons with regard to reliability of his processes and methods. This new field is one in which the integrity of the system being fabricated must be beyond question, since a weld failure, even a minor one, may destroy the usefulness of an expensive plant.

These circumstances have made necessary many new concepts in welding, particularly with stainless steels. We have found it necessary to learn new methods and to change old techniques and procedures. What has formerly been considered sound welding is often not satisfactory for this type work; testing methods formerly employed have been found to be inadequate, and improvements and new nondestructive methods have been adopted.

The result has been a better understanding throughout industry of the requirements for really sound welding. There has been a considerable drive necessary to reach this point, since many would have otherwise remained with an inadequate know-how, but one suitable for an ordinary job. This drive was prompted by some who are in the foreground of the atomic energy program; who were bold enough to insist upon industry using better and advanced procedures. Much still remains to be done to improve welding processes of all kinds. The present atomic-energy program is a good example of the sudden development of needs which go beyond existing methods. It shows that progress must be continuous and that industry and the members of the AMERICAN WELDING SOCIETY must never be complacent concerning their accomplishments.

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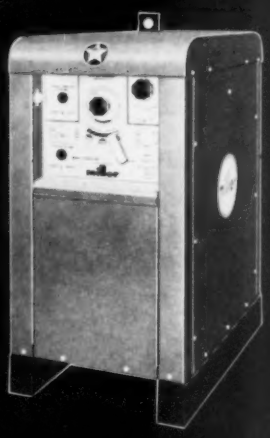

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WELDING CAST COMPONENTS FOR NUCLEAR-POWER APPLICATIONS

BY W. H. RICE

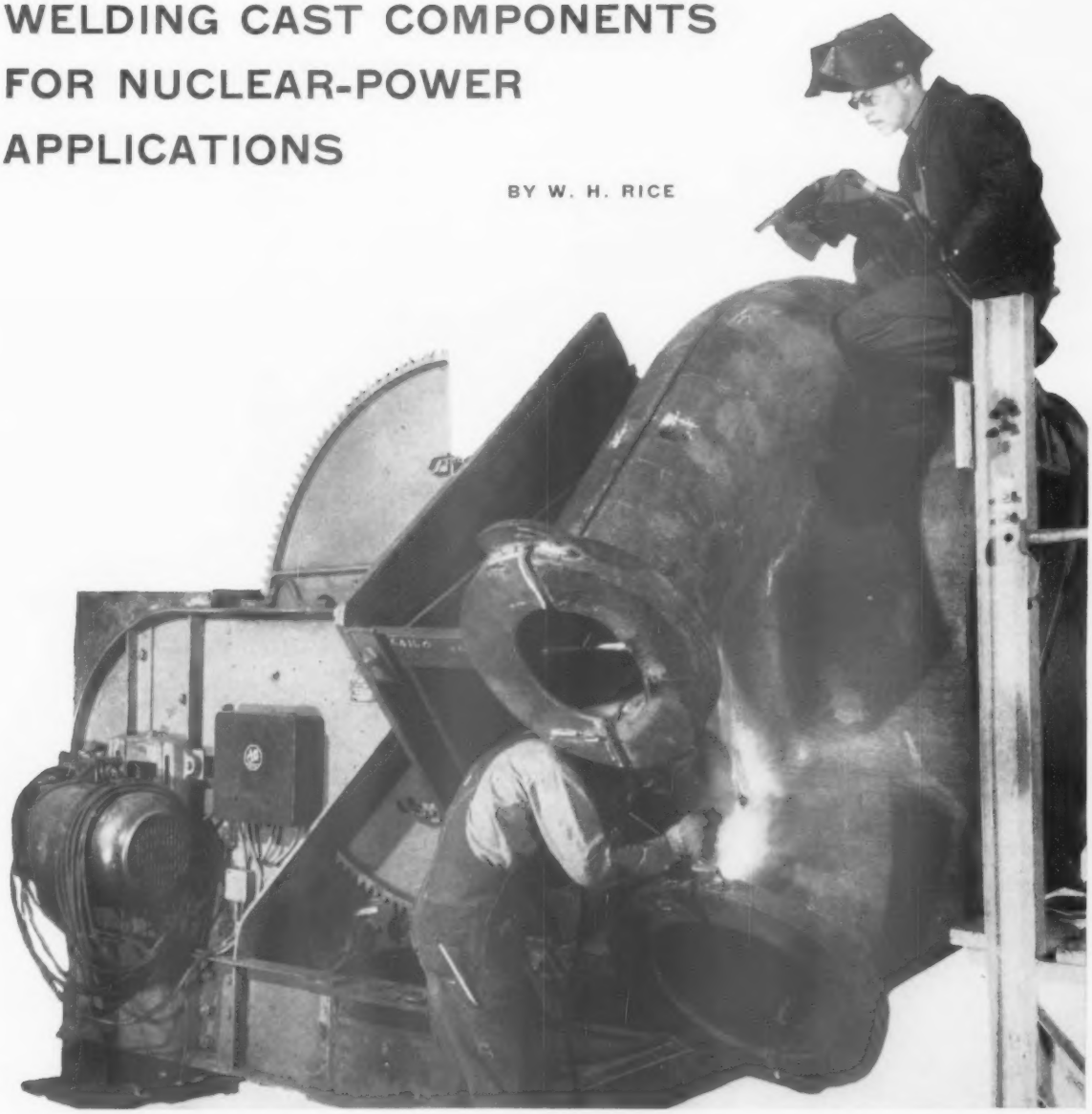

Fig. 1 Welding pump halves together to produce the finished cast weldment

Extensive program is conducted to assure that base metal, weld and fusion zones meet fully the required mechanical and metallurgical properties, both as-welded and after heat treatment

ABSTRACT. The atomic-power program has passed its state of infancy and with the coming months and years will rapidly blossom into adulthood. Specifications for quality control of materials and workmanship are far more rigid than foundries have encountered in the past and are becoming increasingly so as additional information is obtained.

Base materials involved include austenitic and martensitic stainless steels such as ACI-CF-8, CF-8M, CF-8C, CH-10 and CA-15 as well as carbon steel. Additional alloys are being thoroughly investigated for potential future use.

An extensive testing program is necessary to determine if the base metal, weld and fusion zone meet fully the required mechanical and metallurgical properties both as-welded and after heat treatment. Welding procedure specifications normally require use of either metallic covered electrodes or the inert-gas-shielded arc-welding process. Operators must prove their proficiency by passing rigid qualification tests for each type of alloy

W. H. Rice is consultant for Electric Steel Foundry Co., Portland 10, Ore.

Paper presented at the ASME Metals Engineering Division Conference held in conjunction with the 1958 AWS Annual Spring Meeting, Apr. 14–18, St. Louis, Mo.

Table 1—Composition of Typical Cast Stainless-Steel Alloys

Type	C, max	Mn, max	Si, max	P, max	S, max	Cr	Ni	Other elements
CF-8	0.08	1.50	2.00	0.04	0.04	18–21	8–11	...
CF-8M	0.08	1.50	1.50	0.04	0.04	18–21	9–12	Mo 2.0–3.0
CF-3	0.03	1.50	1.50	0.04	0.04	18–21	9–12	...
CH-10	0.10	1.50	2.00	0.04	0.04	22–26	12–15	...
CF-8C	0.08	1.50	2.00	0.04	0.04	18–21	9–12	Cb-Ta 10XC min, 1.35 max
CA-15	0.15	1.00	1.50	0.04	0.04	11.5–14	...	Mo 0.5 max

Table 2—Minimum ASTM Requirements for Cast Steels in Table 1

Type	Tensile strength, psi	Yield strength, psi, 0.2% offset	Elongation in 2 in., %	Reduction in area, %	Hardness, BHN
CF-8	70,000	28,000	35	...	...
CF-8M	70,000	28,000	30	...	...
CF-3	65,000	28,000	55	60	140
CH-10	70,000	30,000	30	...	...
CF-8C	72,000	36,000	35	35	145
CA-15	90,000	65,000	18	30	241 max

used. Weldability evaluation tests are also performed on individual castings in the vicinity of the weld that is to tie the casting into the system.

Close control and inspection must be exercised over each stage of production. This includes joint-groove preparation, sequence of welding, maintenance of preheat and interpass temperatures, cleaning and inspection of each weld bead, grinding craters and between passes, dye-penetrant examination during welding, post-weld heat treatment, machining and radiographic inspection. When castings and cast weldments are ready for shipment they must be as perfect as can be determined by modern inspection devices.

Introduction

The rapidly increasing demand for power, coupled with gradual depletion of natural carbon and hydrocarbon fuels, have necessitated an accelerated program of nuclear-power development by our modern civilized world. Ranking among the foremost in international priority, nuclear projects for both stationary power plants and land, sea and air transportation, require perfection in materials and workmanship heretofore considered impossible to achieve.

The complexity of shape of component parts for atomic-power plants has led to the casting industry as a major supplier. In addition, certain alloys can be economically produced only in cast form due to their hot-short characteristics. Due to the rigid material requirements of the atomic-power program it is now routine practice to produce castings of perfection that would have been considered absolutely impossible but three years ago.

At present, the favorite material used for nuclear pumping systems is stainless steel. The most prominent material is austenitic stainless steel ACI CF-8 although impellers and other auxiliary parts are frequently produced in martensitic chromium stainless steel CA-15. Other alloys used are CF-8M, CF-3, CH-10 and CF-8C as well as various modified analyses of all of the above. Extensive testing programs are being conducted to determine the suitability of numerous other alloys. Even carbon steel has been used to some extent and pumps of this material are currently in test loops. Compositions of the above-mentioned stainless-steel alloys are listed in Table 1, and the minimum ASTM mechanical properties are given in Table 2.

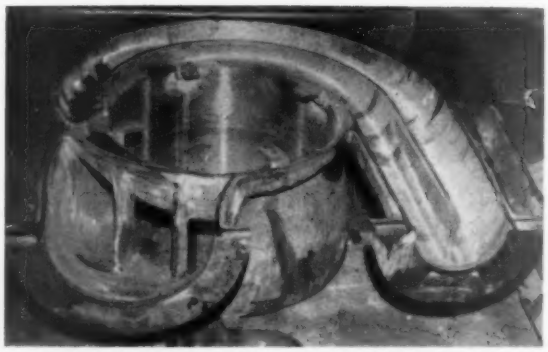

Fig. 2 Half of pump volute with cast-on weld groove

Fig. 3 Finish machining weld groove on volute half shown in Fig. 2

Production Planning

At ESCO, a committee composed of representatives of each production department meets to study full-

sized drawings of each new casting to be produced. At this meeting, pattern construction, coremaking, molding, composition and structure of molding sand, melting practice, cleaning, heat treating, welding and other production factors are discussed in detail.

With all known information and specifications at hand, the project engineer, who has acted as liaison during preliminary planning meetings, must then prepare a detailed estimate of costs, taking into account each stage of production. Any design changes that might result in the improvement of product or economy of production are then presented to the customer for his consideration.

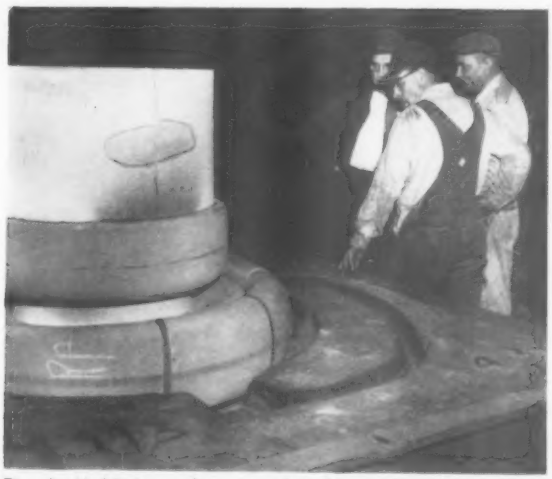

Fig. 4 Mold drag of pump volute for a submarine nuclear-power plant.

Production of Cast Weldments

The fact that small castings of simple shape are of greater soundness and quality than extremely complicated castings has led to the increased demand for cast weldments. A typical example is a pump for a land-based nuclear-power installation produced by the Bingham Pump Company. This volute consisted of two cast Type CF-8 stainless-steel halves to be welded together, one of which is shown in Fig. 2. The contour of the weld groove was cast on the edge to eliminate an undue removal of metal during machining of the finished groove. Machining of this groove with a contour end-mill attachment in a vertical boring mill at the Willamette Iron and Steel Co. is shown in Fig. 3.

The two pump halves were fitted and tack welded together with a consumable insert fitted into the joint for an inert-gas backed tungsten-arc root pass, and mounted on a welding positioner as shown in Fig. 1. The weld was then completed to Class 1 radiographic standards with the inert-gas metal-arc process using $^1/_{16}$-in. Type 308 stainless-steel filler wire at 290 amp. The shielding gas for the inert-gas metal-arc process consisted of argon containing 1% oxygen to produce a spray-type arc. A little pick-up work was necessary around corners with Type 308–15 electrodes which the operator is doing in the foreground.

The drag portion of a mold with inset cores for a pump-volute casting for a submarine nuclear-power plant is shown in Fig. 4. This casting which weighed 3900 lb is being poured in Fig. 5. A nozzle extension was welded to the clean CF-8 casting. After radiography of this weld, the skirt was welded to the casting.

Fig. 5 Pouring the casting of the mold shown in Fig. 4.

Fig. 6 Welding skirt to casting being poured in Fig. 5

This operation, which is being completed in Fig. 6, required 56 hr of welding time using $^5/_{32}$-in. diam AWS E 308–15 electrodes at a current of 120 amp at 25 v. Light grinding with resin-bonded aluminum-oxide wheels was done between passes which were made with a combination of step-back and skip welding procedures using stringer beads.

After grinding, the skirt weld was radiographed as shown in Fig. 7. Both the casting and weld conformed to Class 1 Navy radiographic standards. Radiographic exposures having 1% sensitivity are obtained within a few seconds by means of the recently installed 22 million volt Betatron. This equipment is capable of radiographing steel sections up to 20 in. in thickness.

After heat treatment, machining and final inspection, a volute casting becomes an integral part of a canned pump. A typical canned pump designed and built by the Westinghouse Electric Corp. is illustrated in Fig. 8. This pump is one of four to be used in the primary cooling system of the nuclear-power plant illustrated in the diagram, Fig. 9.

Composition Versus Welding

As the chemical metallurgy of each type of steel is different, so is the physical metallurgy, which accounts for the differences in physical and chemical properties. As heat treatment, forming and mechanical characteristics of each alloy differ, so do the welding characteristics. In fact, very slight chemical alterations of a given alloy frequently exert a vast influence on its response to welding.

Fig. 7 Radiography of the skirt weld illustrated in Fig. 6

Fig. 8 Typical canned pump used in nuclear-power service

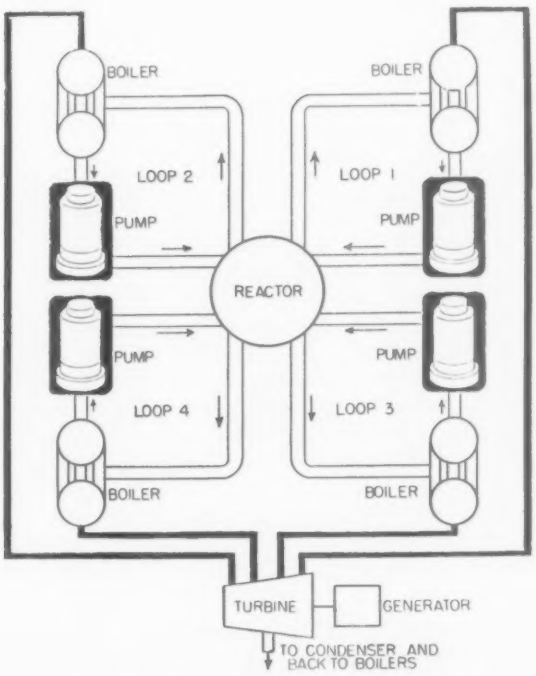

Fig. 9 Diagram of nuclear-power plant in which pump shown in Fig. 8 is used

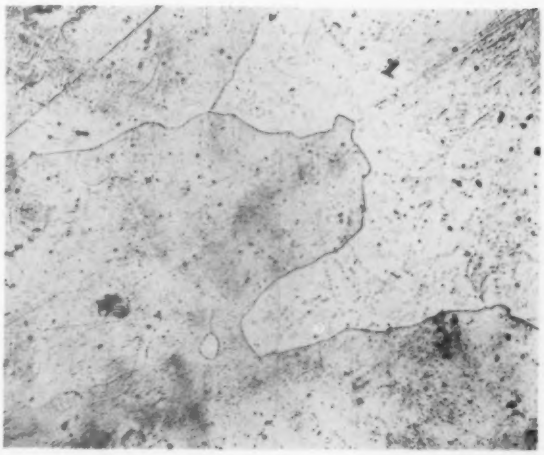

Fig. 10 Fully austenitic structure of CF-8M casting which is difficult to weld without microfissuring. X150. (Reduced by $^{2}/_{3}$ upon reproduction)

For example, the microstructure of an 18% chromium – 12% nickel – $2^{1}/_{2}$% molybdenum stainless steel, balanced chemically so that it is fully austenitic, is shown at a magnification of ×150 in Fig. 10 after sensitization heat treatment at 1600° F. Use of small di-

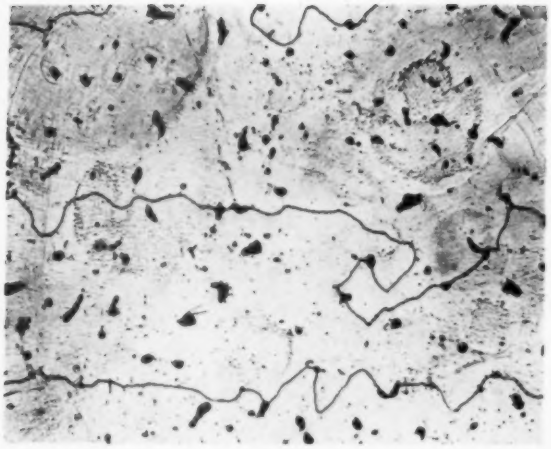

Fig. 11 Essentially the same composition as Fig. 10 containing 6% ferrite which has excellent weldability. X150. (Reduced by $^2/_3$ upon reproduction)

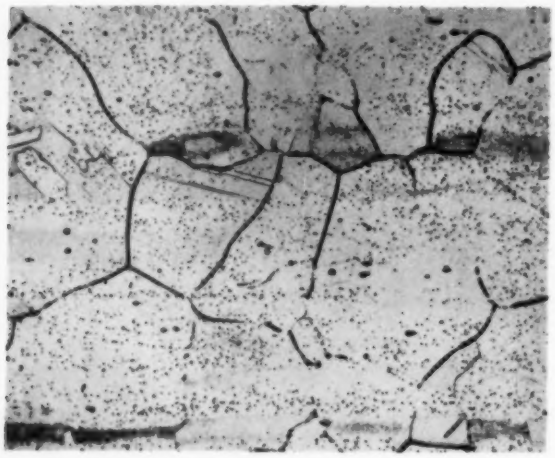

Fig. 12 Intergranular corrosion due to precipitated carbides. X150. (Reduced by $^2/_3$ upon reproduction)

ameter electrodes at quite low current settings, with very low interpass temperature, was necessary to prevent fusion-zone microfissuring. Use of stringer beads, skip welding and moderate peening was also required. The microstructure at the same magnification of a heat made to the same chemical specification is shown in Fig. 11, which contains about 6% ferrite due to a slightly higher chromium and lower nickel balance. It may be noted that the ferrite has been largely converted to sigma phase which is etched black by sensitization heat treatment. The excellent weldability of this heat in comparison with the one previously shown is attributed to the ferrite content.

The temperature service conditions of an alloy must be carefully considered. Chromium carbide forms at temperatures between 800 and 1200° F and precipitates out in grain boundaries leaving the metal adjacent to the boundaries depleted of chromium. This condition, illustrated in Fig. 12, may render the steel susceptible to

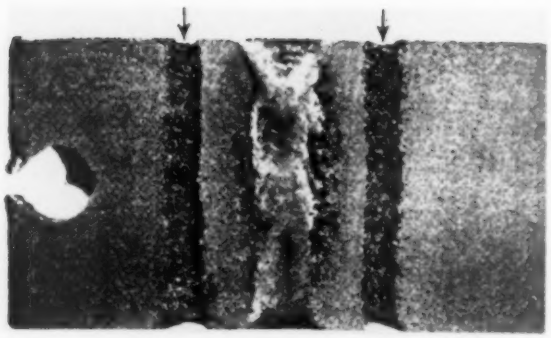

Fig. 13 Result of the condition illustrated in Fig. 12

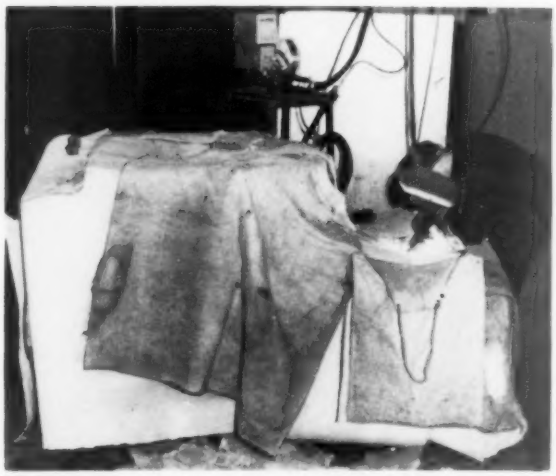

Fig. 14 Martensitic chromium stainless-steel casting preheated for welding. Casting is covered with asbestos to prevent heat loss

certain types of chemical attack along grain boundaries due to an insufficient amount of chromium. This condition frequently exists in the base metal adjacent to raw welds and is commonly referred to as intergranular corrosion or weld decay. A raw weld is shown in Fig. 13 after immersion for an extended period in 25% nitric acid. Chromium-carbide precipitation can be stopped after welding by solution heat treatment at 2000° F followed by water quenching, or by using a stabilized grade of stainless steel. Stabilized grades contain either columbium or titanium which react more readily with carbon than does chromium, leaving chromium dissolved in the base metal for protection against corrosion. Another possibility is the use of low-carbon grades of stainless steel. The carbon content of these grades, less than 0.03%, is not sufficient to cause harmful carbide precipitation. Welding difficulties of the stabilized grades are increasing the popularity of the low-carbon grades.

Qualification of Welding Operators

Only highly skilled operators with many years' experience are permitted to weld castings for the atomic-energy program. These men must demonstrate their

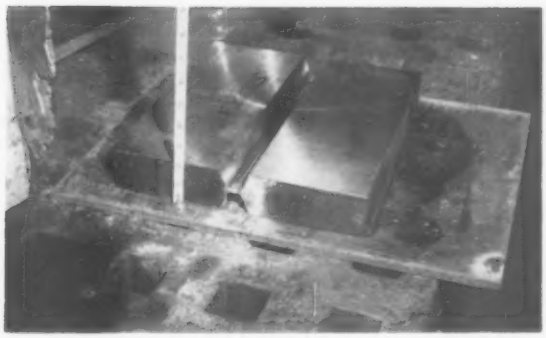

Fig. 15 ASME qualification test plate machined from CF-8 casting 3 in. thick

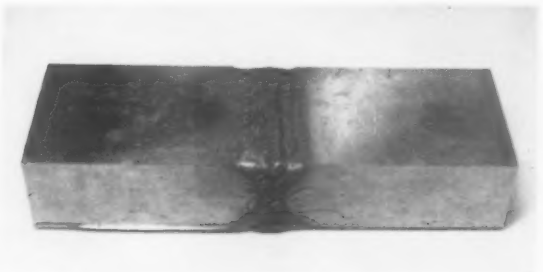

Fig. 16 Section of plate in Fig. 15 after completion of weld

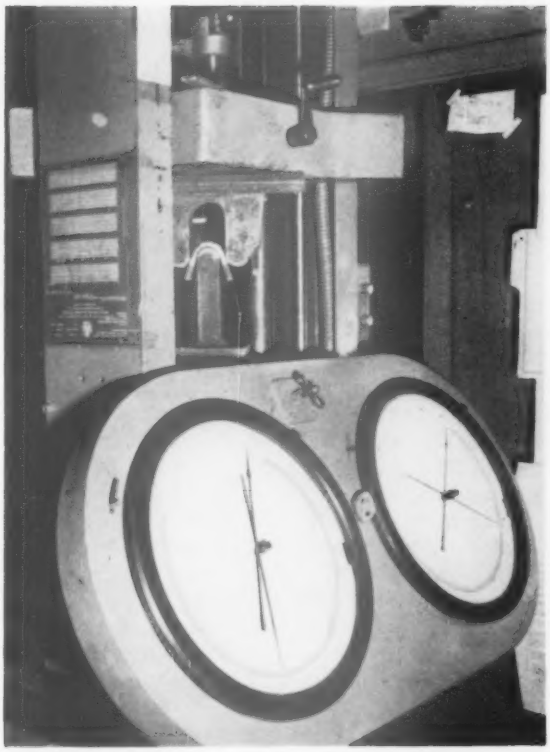

Fig. 17 Standard guided-bend test on bar from plate in Fig. 16

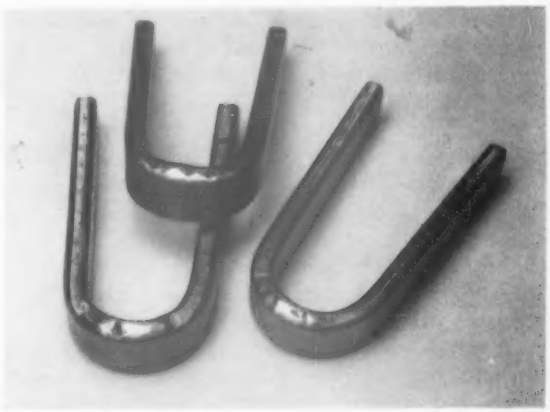

Fig. 18 Bend-test bars from plate in Fig. 16

proficiency by passing various qualification tests. A given operator is required to make numerous tests in accordance with the provisions of individual basic orders, many of which are for military end use. Others are produced in conformance with the ASME Boiler and Pressure Vessel Code, and still others are produced to specifications of individual private companies. In addition, each alloy welded and each position of welding require separate tests.

A procedure specification is written for each alloy produced prior to production welding which includes such items as the welding process, description of filler metal and base metal, position of welding, preparation of base metal, electrical characteristics, details of welding technique such as machine settings and welding sequence, appearance of weld, methods of cleaning, elimination of defects, preheat and postheat, interpass temperature control, heat treatment and inspection.

In order to prove the validity of the procedure, a procedure qualification test must be given. The operator who successfully makes this test is automatically qualified to do the welding. Subsequently, each operator who welds under this procedure must take a similar test or at least a simplified version with fewer test coupons. This procedure may vary greatly according to the alloy to be welded. For example, austenitic chromium-nickel stainless steels, in general, are welded with a maximum interpass temperature which is frequently 200° F, whereas martensitic straight-chromium stainless steels commonly require a minimum preheat of about 600° F which must be maintained while welding. This is illustrated by the casting in Fig. 14, which is covered with asbestos to prevent heat loss during welding. It may be observed that this casting is being welded by the inert-gas metal-arc process.

Typical double-U grooved qualification test plates machined from 3-in. thick castings are shown in Fig. 15. A section of this plate is shown in Fig. 16 after completion of the weld. Two tensile-test coupons from each side of the joint and four side-bend-test coupons from each side were required for this test, which was witnessed by the Oregon state boiler inspector in accordance with Section IX of the ASME code. Figure 17 illus-

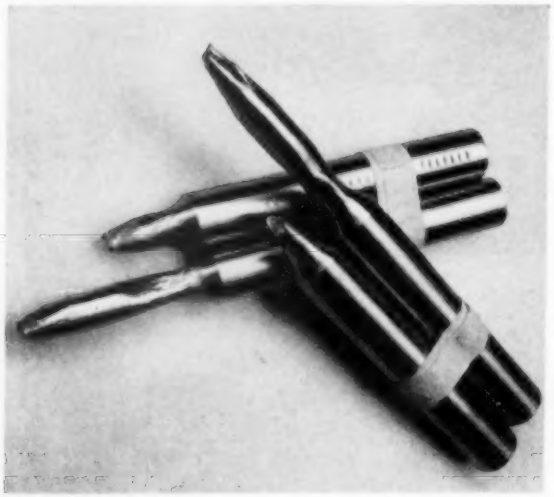

Fig. 19 Tensile-test bars from plate in Fig. 16

trates a standard guided side-bend test being made, and three of the bars are again shown in Fig. 18 after completion of the 180-deg bend. Two of the tensile bars are shown in Fig. 19 with failure in the base metal. The excellent ductility of the base material is denoted by the large percent of reduction of area of the fractured ends.

Quality Control

It is of the utmost importance that careful control of quality be exercised by the supervisory personnel at all times. A fast and common method of maintaining quality control is by visual inspection which requires the use of good lighting and magnification. Visual inspection should consist of examination prior to, during and following welding operations.

Examination prior to welding consists of looking for defects in the base metals and to assure that scale, grease, dirt, paint or other contaminators have been properly removed. Joints are washed with new or redistilled acetone or alcohol followed by rinsing with distilled water and drying with lint-free cloths prior to welding. Inspection is made of fit-up and alignment of parts and joint-edge preparation.

During welding, it is necessary to inspect each pass, after it is deposited, for porosity, cracks, lack of fusion, slag, roughness, undercut, etc. Any such defects must be removed by grinding with rubber or resin-bonded aluminum-oxide wheels or carbide burrs. The only grinding wheels that may be used are new ones or those that have been previously used only on the same type of material. This is to avoid contamination by imbedding foreign particles in the base metal. For similar reasons all brushing of welds is done with stainless-steel brushes that have not been previously used on carbon steel. The root pass in many cases is the most important one, as a notch effect caused by incomplete fusion may lead to failure of the weldment or interfere with decontamination.

After welding, inspection should be made to determine dimensional accuracy, including warpage. The size, continuity, contour and distribution of welds should be in accordance with the requirements of the job. The appearance of the finished weld, such as spatter, regularity, roughness, etc., in many cases provides a clue as to the quality of workmanship. Careful examination should be made for flaws such as cracks, porosity, unfilled craters, ends of welds and undercut. The use of dye or fluorescent penetrants is a valuable aid in discovering cracks or other defects associated with welding. Dye penetrant is normally used on the root bead, at each $^1/_2$ in. of deposited weld metal and on the completed weld.

It is necessary to conduct complete mechanical, metallographic and chemical tests of welds of each alloy produced in a given foundry. If satisfactory results are not obtained, the procedure must be revised and retested until optimum results are obtained. In addition, check tests are periodically required of qualified operators to assure that the quality of workmanship is being maintained. Likewise, any major change in procedure or process must be accompanied by appropriate tests in order to determine its suitability.

Acknowledgment

The author wishes to express his appreciation to the Electric Steel Foundry Co., Bingham Pump Co., Willamette Iron and Steel Co., Westinghouse Corp. and E. I. du Pont de Nemours for assistance in preparation and permission to present the information contained in this paper.

Fig. 1 Turbine-shell casting designed for a separate welded-on steam chest

WELDING LOW-ALLOY STEEL CASTINGS FOR HIGH-PRESSURE AND HIGH-TEMPERATURE SERVICE

Fabrication and repair welding of large alloy-steel castings for use in steam turbines operating at temperatures up to 1050° F and at pressures up to 3500 psi are described

BY N. A. CHAPIN, C. H. SOLDAN AND L. W. SONGER

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ABSTRACT. The service requirements of modern steam turbine-generator equipment necessitate that casting-weldment components have high strength and maximum reliability. Procedures used in processing low-alloy steel components for this type of service are described. The use of manual submerged-arc welding has improved the quality and increased the weld deposition rates. Pre- and postweld heat treatments and the interrelation of casting and fabrication designs are discussed. Also, the importance of complete records and good quality-control practices is pointed out.

Introduction

The design of modern steam turbine-generator equipment has been enhanced greatly by the steady and continued technological growth of welding. It is difficult to conceive of power-generating equipment which does not contain welded components. Present-day high-temperature and high-pressure operating conditions require that components of the highest quality be designed and produced to meet both the demands of service operating conditions and economic manufacture. This paper describes the fabrication and repair welding of large alloy-steel castings for use in steam turbines operating at temperatures up to 1050° F and at pressures up to 3500 psi. These castings vary in weight from 1000 to 80,000 lb.

The composition and heat treatments for these materials are shown in Table 1. The successful use of casting-weldment components has been possible by the application of sound welding procedures and quality control.

The over-all manufacturing steps for a large low-alloy steam-turbine outer-shell casting weldment are outlined in Table 2. The technical aspects of these processing operations will be discussed under four classifications: (*a*) interrelation of casting and fabrication design; (*b*) welding metallurgical aspects; (*c*) welding process techniques and (*d*) quality control and records.

Table 1—Composition and Heat Treatments of Materials

	Nominal chemical analysis, %					
Material	*Cr*	*Mo*	*Mn*	*C*	*V*	*Heat treatments*
Cr-Mo	1	1	0.70	0.20	..	Normalized 1920° F min. Tempered 1250° F min.
Cr-Mo-V	1	1	0.70	0.18	0.20	
Cr-Mo (weld metal)	0.50	1	0.90	0.12		

Table 2—Manufacturing Steps for a Large Steam Turbine Casting Weldment

1. Design.
2. Design review.
3. Produce casting (casting annealed for processing).
4. Casting layout.
5. Rough machine operations and machining of planned weld preparations.
6. Nondestructive inspection of casting.
7. Casting-defect removal.
8. Planned and repair welding.
9. Heat treatment of casting weldment.
10. Final nondestructive inspection of completed casting weldment.
11. Quality control and records (continuous operation during Steps 1–10 above).
12. Final machining.

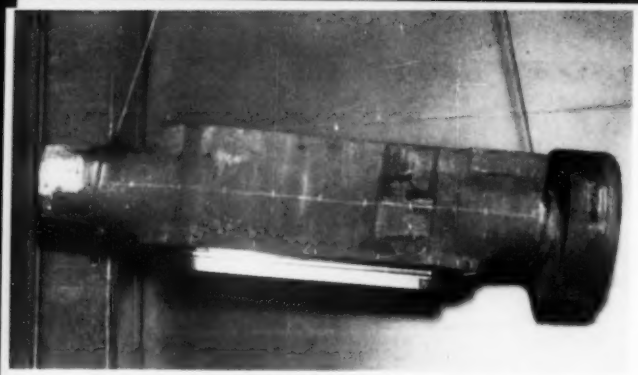


Fig. 2 Steam chest with an integral inlet flange, weld preparations partially machined

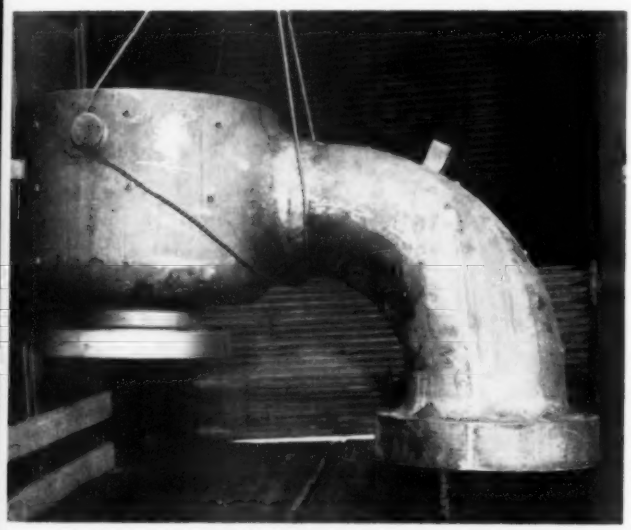


Fig. 3 Valve casing with a separately cast flanged elbow assembly welded

Interrelation of Casting and Fabrication Design with Respect to Welding

Design

Good designs do not happen. They are the result of a carefully thought out, systematic engineering approach to produce a component which will satisfy a given set of conditions. The designer must have a thorough knowledge of cast and wrought materials and be willing to use these materials either singly or in combinations if quality components are to be produced. In addition, he must also consider other equally important design criteria such as structural strength, heat flow or distribution, method of welding, postweld heat treatment, method of finishing and method of nondestructive inspection.

Castings

One of the greatest uses of welding lies in the casting field. In the past, foundries attempted to cast any design which was submitted to them. This meant that heavy sections, particularly in the bottom of the mold, contained shrink or other defects which would not be acceptable under present-day standards. High-quality complex castings are produced today by making the casting in more than one piece for subsequent fabrication. These separate castings can be placed in the mold for proper feeding and directional solidification which is a necessity for high quality.

Figure 1 shows a turbine-shell casting designed for use with a separately cast and welded-on steam chest.

Figure 2 shows the separately cast steam chest.

Figure 3 shows a valve casing with the separately cast flanged-elbow assembly welded.

In each case the over-all quality was greatly improved as the individual castings were made in the most advantageous position from the casting viewpoint.

Many complex projections poured as a part of the casting are also a continuous source of unacceptable casting defects. These components can be improved by making individual fabrications or castings of these projections and then welding the separate parts to form a high-quality assembly.

Higher-quality components can be made by using better-quality individual parts which have been made from the best-suited material in the most economical manner and welded together. Since welding is a costly manufacturing operation, however, no component should be cast in more than one piece and welded if it is possible to cast a single piece of the required quality.

Weld Preparations

The guiding thought in the design of all types of weld preparations is to obtain fusion throughout the entire wall thickness, while at the same time keeping weld shrinkage and the attendant locked-up stresses and distortion to a minimum. To secure full penetration on a consistent basis, proper access to the root is a prime requisite which allows the welder to follow the welding progress and to maintain control of the arc. This control is particularly significant where lack of

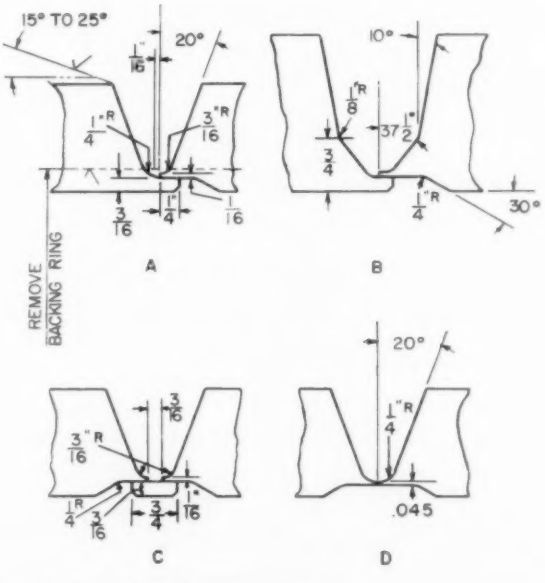


Fig. 4 Typical weld preparations

penetration or excessive penetration causes defects on the inside of the joint which cannot be corrected by removal and rewelding from the inside. To minimize shrinkage, distortion and fabrication costs, it is desirable to keep the amount of deposited weld metal to a minimum. These requirements, together with the welding process to be employed and any special conditions imposed by the specific application, must receive careful consideration.

Figure 4 shows typical weld preparations for joining heavy-walled sections. Illustrations A, B and C show weld preparations used for manual metal-arc welding, and for manual or mechanized submerged-arc welding. Illustration D shows the preparation for inert-gas metal-arc welding of the root pass. This preparation can be used either with or without a consumable backing ring. Backing rings of either the integral or separate type are machined out where possible, Fig. 4A. It is also advantageous to machine a secondary angle on the outside diameter of castings, Fig. 4A, to insure uniform weld thickness by having a uniform outside diameter.

Welding Metallurgical Aspects

Preheat

Welds which have a high degree of restraint and high residual stresses are encountered during fabrication and repair welding. The size of the planned welds ranges from 1 to 6 in. in thickness, many being in the 3 to 6 in. range. Also, the usual contour of casting-defect repair welds is of an elliptical cup shape, and can be in heavy over-all sections, sizes up to 24 in. in thickness. In large section sizes, high multiaxial residual welding stresses can cause material failure with little deformation.

For planned and repair welding, the components are preheated to 450° F minimum. This temperature is above the impact transition temperature of the base metals. Note Fig. 5.

The impact test is an indication of the resistance of the material to triaxial stresses under a notch. As mentioned above, repair welds in large sections can have high triaxial residual stresses. The use of preheat above the impact transition temperature holds the material in a temperature range in which its resistance to failure under triaxial stresses is increased.

Experience indicates that the maintenance of the preheat during welding is imperative to the successful processing of these highly restrained welds. Furthermore, it is advantageous to continue the preheat temperature until postweld heat treatment can be effected. This eliminates the possibility of having welds with high residual stress subjected to temperature ranges where their resistance to crack propagation is decreased.

Heat Treatments

The main objectives of subcritical postweld heat treatments are to relieve residual welding stresses and temper hard heat-affected zones. By raising the weld to a high temperature, the yield strength of the material is lowered and a relaxation of the residual stresses is accomplished. The temperature and the time at the temperature are the main variables of a stress-relief cycle. The temperature is a more important variable here than the time at temperature.

The Cr-Mo and Cr-Mo-V steels considered in this paper are given a subcritical stress-relief cycle at 1275° F.

In base metals whose heat-affected zones are subject to secondary hardening, the time at temperature is also an important variable. This time must be long enough to temper the heat-affected zone through its secondary hardening peak to a lower hardness approaching that of the base metal. The Cr-Mo-V steels considered in this paper are subject to this type of hardening, and are tempered satisfactorily by 8 hr at 1275° F. Reference 1 further illustrates this point.

The components under consideration have great variation in section sizes. This necessitates carefully planned furnace loading and thermocoupling to assure that all sections receive the proper time-temperature cycle.

Some large turbine castings are processed in the fully annealed condition during repair and planned welding. The advantages of processing castings in this condition are: lower as-welded residual stresses, greater crack-propagation resistance, and a more complete relief of residual welding stresses by a final above-critical heat treatment.

The annealed chromium-molybdenum castings have an average room-temperature yield strength in the range of 45,000 psi, while the normalized-and-tempered chromium-molybdenum castings have a room-temperature yield strength in the range of 70,000 psi. This favors lower as-welded residual stresses for welds made in annealed base metal.

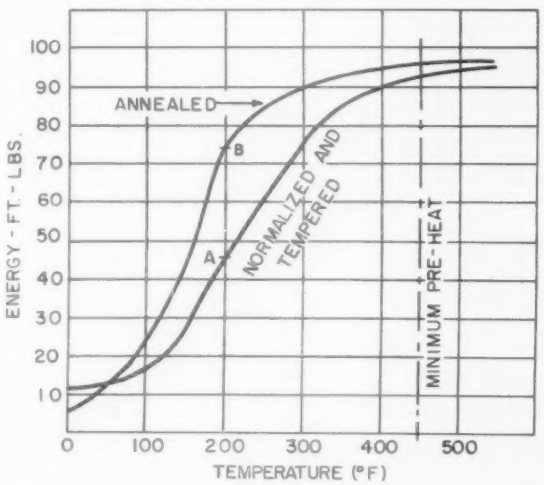


Fig. 5 Typical impact transition curves for 1Cr-1Mo-$^1/_4$V cast material

Figure 5 shows typical impact transition curves for the same analysis of annealed and fully heat-treated (normalized - and - tempered) chromium - molybdenum-

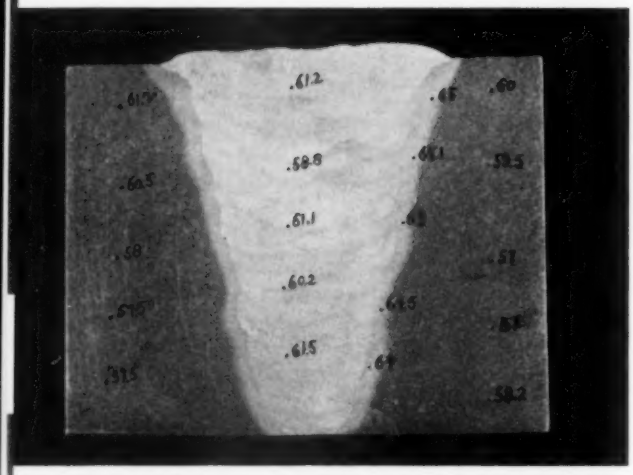


Fig. 6A Photomacrograph of $^1/_2$Cr-1Mo weld in 1Cr-1Mo-$^1/_4$V base metal prior to normalize-and-temper heat treatment. Rockwell "A" hardness survey. Magnification X $1^1/_4$. (Reduced by $^1/_3$ upon reproduction)

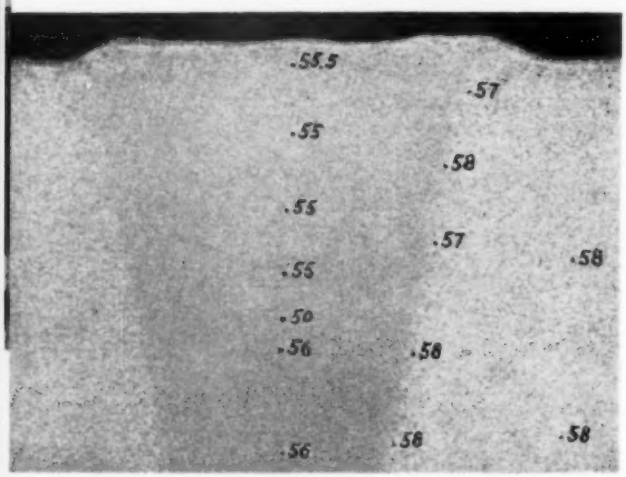


Fig. 6B Photomacrograph of $^1/_2$Cr-1Mo Weld in 1Cr-1Mo-$^1/_4$V base metal after normalize-and-temper heat treatment. Rockwell "A" hardness survey. Magnification X2. (Reduced by $^1/_3$ upon reproduction)

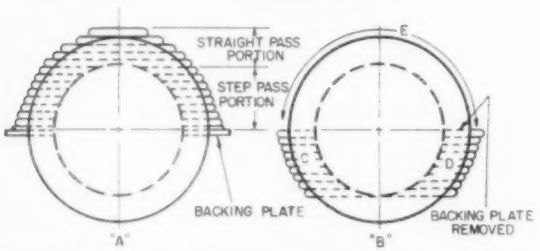


Fig. 7 "Step-Pass" submerged-arc welding of a circumferential weld

vanadium material. The transition temperature is lower for the annealed condition. The main difference to be cited, however, is the greater energy-absorption capacity of the annealed material. At 200° F, the normalized-and-tempered material has a value of 45 ft-lb versus 74 ft-lb for the annealed material. Note Points *A* and *B* on Fig. 5. This indicates a greater crack-propagation resistance for the annealed condition in this temperature range. It is difficult to maintain full preheat on some of the very large castings (i.e., 80,000-lb large turbine shells), which require considerable handling time to reposition for further welding. The annealed material will, therefore, be less subject to repair weld cracking when it is not possible to maintain a full preheat temperature until a postweld heat treatment is performed. Experience in the authors' plant has generally verified this aspect.

The normalize-and-temper heat treatment, after all planned and repair welding, assures complete relief of residual welding stresses. After a stress-relief cycle which is a subcritical anneal, the level of remaining stresses approaches the yield strength of the materials at the stress-relieving temperatures. In many cases, these stresses can be as high as the working stresses. Service experience has indicated sound weld deposits with high-temperature, stress-rupture failures. It is believed that residual welding stresses contributed to these difficulties. The assurance of complete stress relief by the postweld normalize-and-temper heat treatment minimizes cracking. This is of particular importance where heavy section sizes are subjected to high thermal stresses in service. The normalize-and-temper heat treatment also completely eliminates the heat-affected zone and any "metallurgical notches" associated with it, Fig. 6*A* and *B*.

Further welding metallurgical details pertaining to the chromium-molybdenum-vanadium composition are summarized in Reference 1.

Distortion and scaling are experienced during the normalize-and-temper heat treatment. By the use of tie bars, planned furnace loading and the allowance of extra stock for finish machining, these effects are overcome.

Intermediate Stress Relief

The removal of casting defects by flame gouging can build up high residual stresses and hard heat-affected zones in one area. By using an intermediate subcritical stress relief, it is possible to minimize these so that subsequent defect removal or repair welding can be done without cracking difficulties.

It has also been found beneficial to use an intermediate subcritical stress relief during the repair welding of large areas in locations where high restraint is encountered.

Electrode Composition

The chemical analysis of the deposited weld metal used for the above casting compositions is shown in Table 1. Only low-hydrogen-type covered electrodes are used for metal-arc welding. The majority of the welding, however, is done by the submerged-arc process. At present, work is being completed on the development of chromium-molybdenum-vanadium weld deposits.

Welding-Process Techniques

The fabrication and repair of large castings were ac-

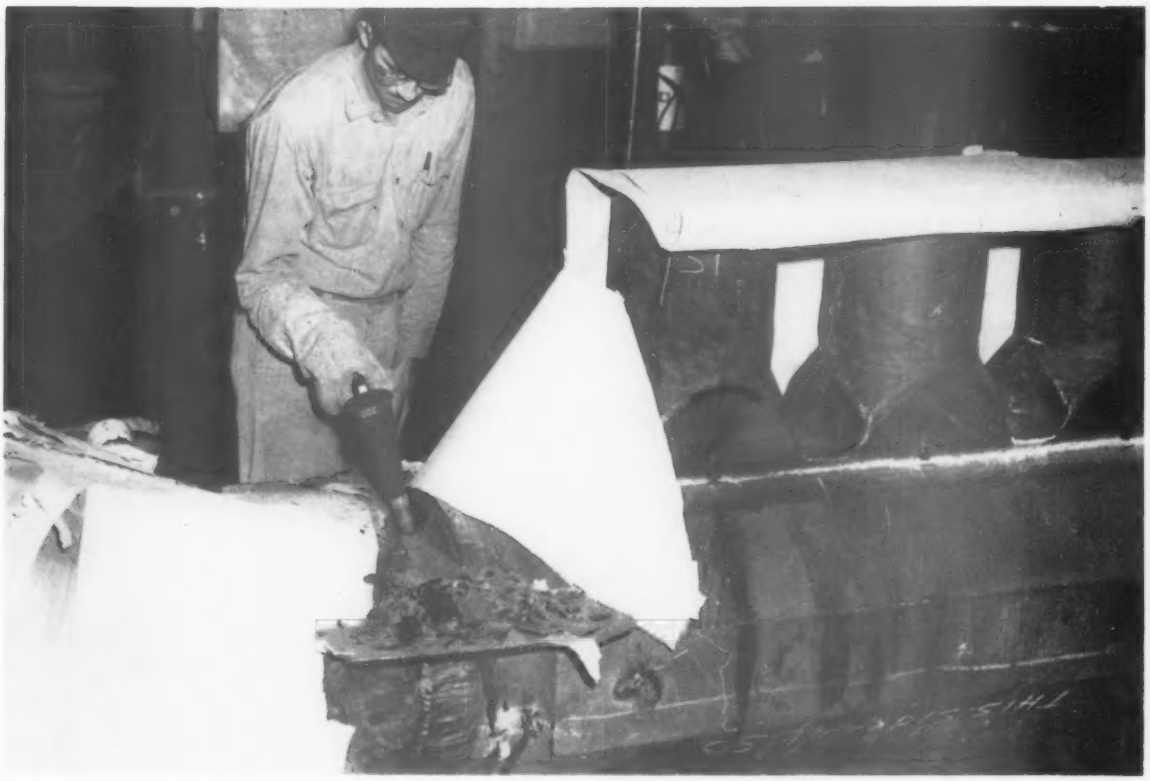


Fig. 8 Stop valve casing being welded to a separate steam chest, using the step-pass method

complished through the use of the following processes: manual metal-arc, manual inert-gas metal-arc, mechanized submerged-arc and manual submerged-arc. Of these, we shall emphasize the techniques which utilize a combination of manual metal-arc and manual submerged-arc welding. This will illustrate the manner in which these processes act to complement each other. All submerged-arc welding is done using $^5/_{64}$-in. diam electrode with currents in the range 300–550 amp and 30–55 arc volts.

It is important to note that a written procedure is prepared for each specific application. Test joints are welded using these procedures and are evaluated prior to release of the procedure for production use.

All welders are qualified in the processes and procedures which they will use in production. A large portion of planned and repair welding is accomplished using manual submerged-arc welding. For this work welders have been trained and qualified in both manual metal-arc and manual submerged-arc welding. We use a qualification procedure for manual submerged-arc welding which includes radiographic evaluation. Assignment of these welders is controlled so that only one welder works on any weld from its beginning to its completion. This method makes one man responsible for the quality of the entire weld.

"Step-Pass" Technique

The name "step-pass" refers to a special technique used for the manual submerged-arc welding of a circumferential butt joint in a pipe having a fixed horizontal axis. This technique consists of welding a series of short layers, beginning at the 3 and 9 o'clock positions and proceeding to the top. This is illustrated in Fig. 7*A*.

This technique is being extensively used in the welding of connections (such as flanged elbows, etc.) to large castings where it is impracticable to rotate the workpiece for mechanized welding. This is applied to connections of wall thickness above $1^1/_4$ in. and inside diameters 6 in. and above.

Figure 8 shows a stop valve being welded to a separate steam chest, using this technique. It is readily seen that rotation of the workpiece would pose a major problem. Production experience has shown that connections can be welded, using the step-pass technique in approximately 60% of the time required for manual metal-arc welding. This includes allowance for positioning.

Manual metal-arc welding is used to weld the bottom portion of the groove until a minimum root width of $^1/_2$ in. is obtained. Backing plates also are welded on in a location slightly below the center of the weld, Fig. 7*A*.

The manual submerged-arc welding of the step-pass portion consists of alternating passes of fillet welds and flat beads. The weld is completely cleaned between each pass. Each layer consists of a fillet weld followed by a flat bead. The direction of travel for these beads

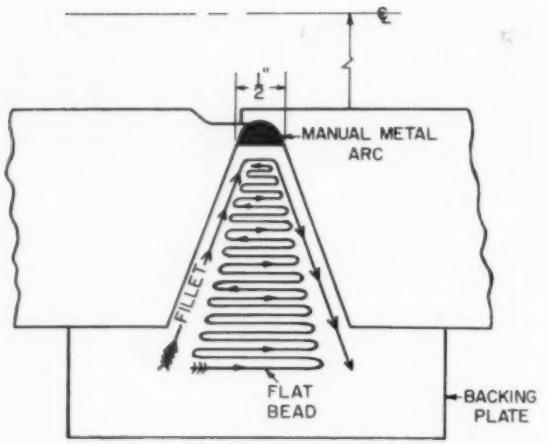


Fig. 9 Top view of a layer of step-pass welding showing the direction of travel

is shown in Fig. 9.

Figure 10, *A* and *B*, are photographic illustrations of such a layer.

With manual submerged-arc-welding procedures, heat inputs approaching 200,000 Joules per inch may be realized. After a short welding time, the adjacent-base-metal temperature rises rapidly. It has been found helpful to limit the interpass temperature to 750° F to ease the complete removal of fused slag. Therefore, the welder frequently moves from one side of the connection to the other during the step-pass portion of the weld, thus allowing one side to cool while welding the other. When the straight-pass portion is reached, the welding current is increased and the groove is completed in multipass layers. Bead thickness for both the step-pass and straight-pass portions is limited to $\frac{1}{4}$ in. to control the molten metal.

Upon completion of one-half of the weld, the work is turned over, backing plates are removed by gouging, the gouged portion is ground and magnetically inspected, and the other half is then welded. When the weld thickness is 2 in. or above, an additional positioning of the work is done to permit welding on the second half of the weld before completion of the initial half. This turnover is usually accomplished when the step-pass portions of the initial half have been completed. Note areas *C* and *D* of Fig. 7*B*. Area *E* is now ready for welding.

After completion of welding, the entire joint is dressed, using flame gouging, powder washing and grinding.

Transition Welds

The welds between thin-walled connections and large castings are sometimes composed of a basic groove plus a transition weld. This is illustrated in Fig. 11.

These welds are made with the axis of the connection in the fixed vertical position, using a combination of manual metal-arc and manual submerged-arc welding. The inside diameter of the connection varies from 6 to 42 in. The basic portion of the weld is completed, using manual metal-arc welding and assembling a flux

Fig. 10 Step-pass weld beads. A—Fillet bead B—Flat bead

dam. The transition portion is then completed, using manual submerged-arc welding in a series of beads as shown in Fig. 11. It is necessary for the welder to exercise care in maintaining a reduced current and a controlled flux depth to insure quality workmanship. Figure 12 shows a weld being made on a large turbine shell utilizing this technique.

After completion of the weld, it is dressed using flame gouging, powder washing and grinding.

Repair Welding

Approximately 90% of repair welds are made by using the manual submerged-arc process. Manual metal-arc welding is used only on small areas and for contouring larger areas to make a satisfactory preparation for manual submerged-arc welding or postweld heat treatment.

A generalized procedure has been written and is followed by the welders for normal repair welding. For areas of increased volume or under especially severe restraint, special welding-sequence instructions are written and issued to the welding and quality control personnel.

Repair welding is usually accomplished by using bead sequences similar to those shown in Fig. 13. Note that beads start at the outside circumference of the cavity.

Figure 14 shows a repair weld being made in a large casting by using manual submerged-arc welding where the usual bead sequence could not be followed and multiple positioning was necessary.

Other Techniques

Increased emphasis is being placed upon improve-

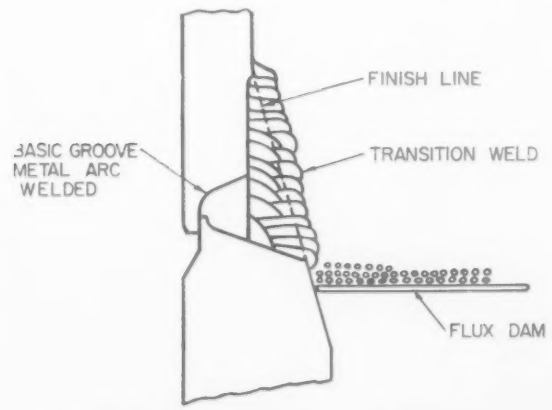
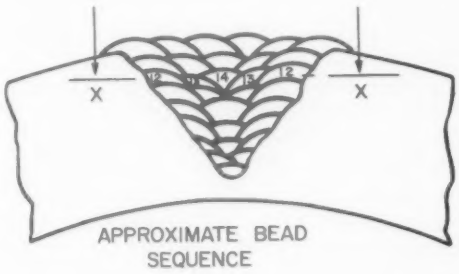


Fig. 11 Bead sequence for transition welding



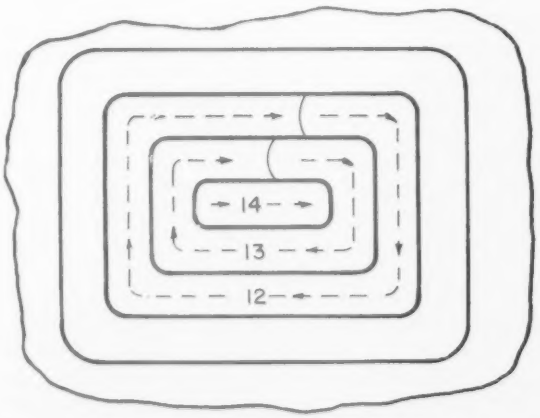


Fig. 13 Bead sequence for submerged-arc defect welding

Fig. 12 Transition welding a connection to a turbine-shell casting

Fig. 14 Repair welding of a large casting, using manual submerged-arc welding

ment of groups of processing operations rather than the piecemeal improvement of individual operations. With the increased deposition rates inherent to high-current-density submerged-arc welding, the welding time is frequently a small portion of the over-all processing time. Therefore, attention has been given to the reduction of over-all processing time rather than a reduction in welding time only. Studies of certain components have revealed that over-all processing economies and advantages could result from the use of a mechanized welding technique in which circumferential welds are made by rotating the welding head rather than the workpiece. Therefore, procedures have been developed for mechanized submerged-arc welding a circumferential weld from one side with the axis of the workpieces in a fixed vertical position. The welding head revolves during this process. All welds made using this technique must pass X-ray evaluation.

Figure 15 illustrates this technique and Fig. 16 is a macrosection of a weld made in this position.

Quality Control

Quality control in welding is an effective system for insuring that welds are made according to established procedures and provides a means for measuring the results. It gives an up-to-date record of performance and conditions so that quality standards can be continuously maintained. The welding of heavy-walled, alloy-steel, pressure-containing parts requires a great degree of precaution and closely controlled welding practices. Therefore, a definite quality-control program is imperative.

While the quality of pressure-containing castings has improved considerably during the past five years, the operating temperatures and pressures have also increased, necessitating a higher casting quality. Casting repair welding is a normal, accepted part of the manufacture of high-quality pressure-containing castings and is generally necessary in order to maintain required standards. Defect repairs may range from minor welding for appearance to complete penetration of the walls, as previously mentioned. However, repair welds in heavy or restrained sections receive the utmost consideration.

Nondestructive Inspection

Castings are cleaned and rough machined before any nondestructive inspection is made. Turbine castings, planned and repair welds are subjected to the following inspections:

1. Visual.
2. 100% magnetic inspection (ferritic materials).
3. 100% liquid penetrant (nonmagnetic materials).
4. Radiographic.
5. Hydrostatic test of pressure components.

Radiographic equipment used includes: 20 Mev Betatron, 1,000,000 v X-ray and 250,000 v X-ray. Stereo-

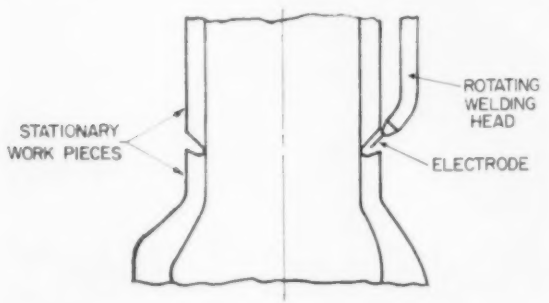


Fig. 15 Mechanized submerged-arc welding of a circumferential butt weld

Fig. 16 Photomacrograph of a mechanized submerged-arc circumferential butt weld. Magnification X2

scopic radiographs are used to a considerable extent in determining the exact location of defects with respect to wall surfaces. This knowledge of the location of the defect saves excessive metal removal since it indicates from which surface to initiate defect removal.

Disposition of Defects

The following evaluations are considered in determining the final disposition to repair or condemn each component:

1. Location and size of defect.
2. Orientation with respect to other defects.
3. Proof that the defect has been completely removed.
4. Service experience.
5. Stress consideration (static and thermal).
6. Limitation of inspection methods.
7. Accessibility for welding.
8. Machining and heat-treatment status.
9. Strength of repair weld.
10. Economics.

Shallow surface defects may be faded out and blended into the surrounding surface where location and stress levels permit and where satisfactory appearance can be maintained.

Contour of Weld Preparations

The main factor controlling the final contour of the weld preparation for a defect is the removal of the minimum metal which will provide a satisfactory weld preparation.

Three things that must be considered for a good weld preparation are:

1. The position in which the defect is to be welded.
2. The process to be used.
3. Freedom from undercut areas that may cause slag pockets during welding or difficulty in cleaning.

The finished surface of all defect areas, whether repair welded or faded out, must blend into the adjacent surfaces to form a smooth contour. It has also been found necessary to blend all large repair weld areas prior to any postweld heat treatment. This minimizes stress concentrations which may promote cracking during postweld heat treatment.

Records

Process welding on high-temperature components is of such importance that each weldment is processed as an individual part and complete records of all inspections, welding procedures and postweld treatments are maintained. It is requisite that the following records be maintained in order to insure quality control:

1. Name and drawing number of part.
2. Material, heat-treated condition, source of supply.
3. Serial number of each part.
4. Nondestructive inspection of weld preparations before welding.
5. Preheat.
6. Welding procedure, including electrode and method of welding.
7. Identification of welder for each weld and operator-qualification records.
8. Photographic record of all defect locations.
9. Tabulation of the size of each defect.
10. Record of nondestructive inspection of each weld. (Radiographic, magnetic).
11. Record of postweld heat treatments.
12. Final mechanical inspection of welds.
13. Planned welds on steam-turbine parts subjected to pressure must be certified and copies of the certification must be maintained.

These records give a continuous measure of weld quality, how well the written procedures are followed, and a reliable means for relating service experience with shop procedures.

Conclusions

Sound welds can be made in heavy-walled, low-alloy steel castings by the metal-arc welding processes if closely controlled procedures are followed. The process to be used must be selected to suit the size of the component and the position in which it is to be welded. Manual submerged-arc welding is especially suited to repair and planned welding and also will complement the other processes. Heat treatment, both pre- and postweld, plays an important role in final quality and serviceability of welds. Consideration of sound foundry practices and provision for accessible welds, which can easily be nondestructively inspected, are design requirements. Higher-quality components can be made by using better-quality individual parts, which have been made from the best suited material, in the most economical manner and welded together. The importance of quality control in welding of high-pressure, high-temperature cast weldments is paramount.

Acknowledgment

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When this paper was written, the authors included information and expressed opinions believed to be correct and reliable. Because of the constant advance of technical knowledge, the widely differing conditions of possible specific application and the possibility of misapplication, any application of the contents of this paper must be at the sole discretion and responsibility of the user.

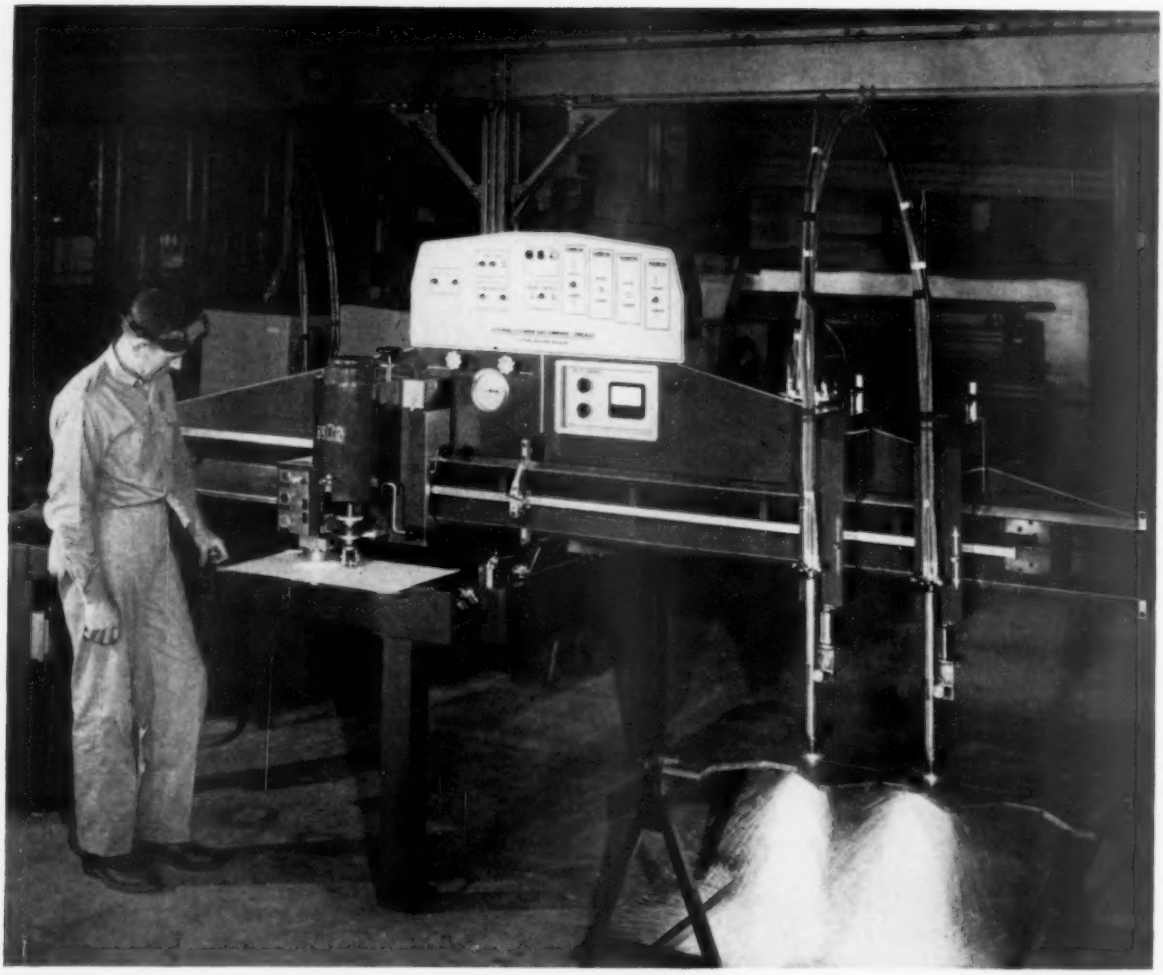

Fig. 1 The motion of two torches on this oxygen shape-cutting machine is being controlled automatically by an electronic line tracer scanning the drawing on the pattern table at left

AUTOMATIC LINE TRACING IN OXYGEN SHAPE-CUTTING MACHINES

Electronic system developed for following the lines of ordinary pattern drawings, rather than black-white edges on specially prepared edge patterns or templets

BY A. F. CHOUINARD AND E. L. McDONALD

Automatic pattern tracing has long been recognized as a fundamental step in achieving optimum production economy in the use of oxygen shape-cutting machines. Reduced production cost, through substantially greater output for each machine and operator, and improved accuracy and repeatability in oxygen shape cutting far outweigh the greater initial cost of automatic equipment. Electronic edge-tracing systems have been available several years for controlling torch motion on oxygen shape-cutting machines, although manual-tracing methods are still far in the majority.

Recently, an electronic system has been developed for following the lines of ordinary drawings, rather than

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black-white edges on specially prepared edge patterns or templets. The new system's simple action of tracing a line will substantially reduce the cost of pattern preparation—initial users have estimated at least 75% —and simplify the use of automatic oxygen shape-cutting machines.

In Fig. 1, the motion of the two torches on a standard oxygen shape-cutting machine, designed originally for manual guidance of the tracing head, is being automatically controlled by a line tracer scanning the drawing on the pattern table at left.

Lower Pattern Costs

The optical scanning system of the electronic line tracer simply follows the exact center of any drawn line 0.040 in. wide or less. The lines may be drawn with standard drafting pencils or ink on any type of drawing paper. The line tracer in Fig. 1 will scan a line continuously with a lateral error of the tracing head less than 0.005 in. in either side of the scanned line at speeds up to 25 ipm and can execute turns down to a minimum radius of $^3/_{32}$ in.

When two lines of a pattern being traced cross each other, the line tracer will continue to follow the proper line, as long as the smallest angle between the lines exceeds 45 deg. The ability of the line tracer to cross its own path provides the pattern designer with far more freedom in using the pattern space available and fewer complications in pattern design, characteristics which are particularly useful in designing tightly nested patterns.

The shape drawings used in line tracing may be saved, stored and reused in the same manner as an ordinary engineering print. Because the inherent tracing error in line tracers is so small, even on sharp corners and at high speeds, the pattern is drawn exactly as it is expected to be reproduced, after making allowances for the kerf width. There is no need to plan and save special patterns to compensate for the nature of the tracer motion; a reference library of control peculiarities is unnecessary. Since an original full-sized drawing is used, there is no need to cut opaque paper for layout silhouettes or to apply black paint on templets. In addition, there is no investment either in masonite or sheet metal for templets, and it is never necessary to change or shield templets during a cut.

Lower Operating Costs

There are several ways in which the line-tracing system reduces the cost of setting up and operating automatic oxygen shape-cutting machines. The optical scanning system is not sensitive to or affected by ambient light. Oxygen shape-cutting machines may be located entirely on the basis of maximum production convenience and availability of space, without regard for the amount of light in the area or without constructing light shields or temporary walls of any kind.

There is considerable gain in flexibility of the outline which may be traced, particularly when extensive chain patterns are involved, because two lines or points in the pattern can be as close together as is necessary. For example, in the chain pattern for gussets in Fig. 2*a* the cutting path at the top and bottom corners of the gussets are separated by only the kerf width (which would be $^5/_{64}$ in. in $^1/_4$-in. steel plate). As the cutting torch passes a following corner, the previous gusset is dropped off—a sequence which occurs for each succeeding gusset in the chain. However, because edge tracing requires a minimum black (or white) path width of $^1/_8$ in., it is possible only to cut through the corners at either the top or bottom of the gusset chain, as shown in Fig. 2*b*. Cutting of gussets on a line tracer then eliminates the hand cutting of the remaining corners to drop the pieces out of the pattern. It is evident also in Fig. 2*b* that the gusset patterns for edge tracing must vary alternately in size in order that the cut pieces be the same size. The line tracer, on the other hand, cuts the work exactly as drawn.

Because the line tracer only senses the location of the line, it is not affected by the considerable variations in the contrast between the pattern lines and paper. The movement of the scanning head is not disturbed by smudges and scratches on the pattern drawing. A dark smudge may momentarily reduce the strength of the steering signal produced in the tracing head but will not affect its motion in any way. If the smudge or scratch over the pattern line is virtually black, the line tracer will simply stop. An edge-tracing device, of course, may go out around an intersecting smudge or follow a scratch off the edge, with the possibility of spoiling the workpieces in either case. Thus, the operator need not be nearly as careful in handling storing and setting up a line pattern for the shape cutter.

To start a shape-cutting operation, the "left," "drive" and "right" buttons on the control panel of the line tracer (Fig. 3) are used to steer the tracing drive wheel toward the line on the drawing. The "auto-off-man" switch is then changed from manual to automatic operation. The "drive" button is de-

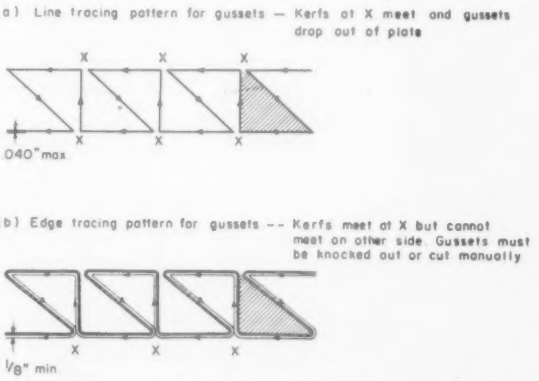
(a) Line tracing pattern for gussets — Kerfs at X meet and gussets drop out of plate
X
X
X
X
X
X
.040" max
(b) Edge tracing pattern for gussets — Kerfs meet at X but cannot meet on other side. Gussets must be knocked out or cut manually
X
X
X
1/8" min

Fig. 2 Tracing patterns for chain cutting identical gussets are compared for line tracing (a) and edge tracing (b). Because two lines in the pattern can be as close together as necessary, the line pattern is designed so that each gusset drops out as the kerfs meet at the top and bottom corners

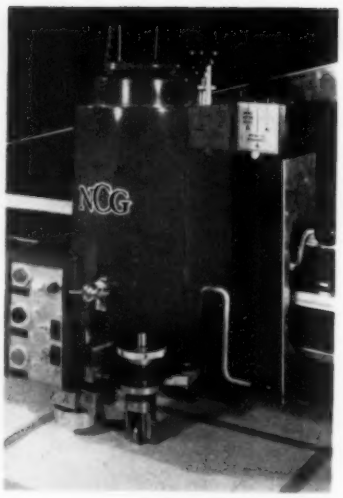

Fig. 3 Control panel of the electronic line tracer includes simple button controls for starting a shape-cutting operation and a single switch for changing to completely automatic tracing

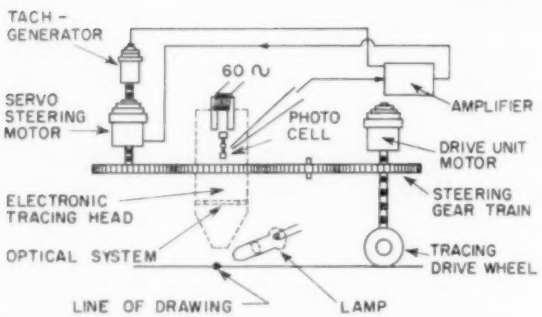

Fig. 4 Schematic drawing shows basic components of the electronic line tracer. A steering signal developed in the photo cell is fed to the servo steering motor, which steers the tracing drive wheel through a gear train

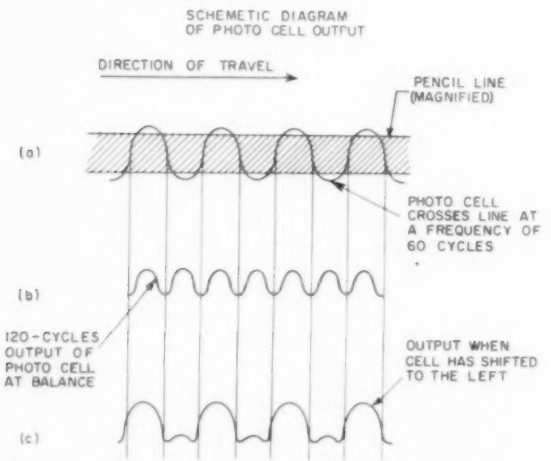
SCHEMETIC DIAGRAM OF PHOTO CELL OUTPUT
DIRECTION OF TRAVEL
PENCIL LINE (MAGNIFIED)
(a)
PHOTO CELL CROSSES LINE AT A FREQUENCY OF 60 CYCLES
(b)
120-CYCLES OUTPUT OF PHOTO CELL AT BALANCE
OUTPUT WHEN CELL HAS SHIFTED TO THE LEFT
(c)

Fig. 5 Schematic drawing shows the development of the steering signal in three steps: (a) 60-cps vibration of the scanning photo cell across the tracing line; (b) 120-cps output of the cell when normally centered through the optical system on the tracing line, as in (a); and (c) output of the cell when it has shifted to the left and more light is transmitted to the cell from the left side of the line. In (c), the larger 60-cps pulse is the steering signal, its magnitude increasing with the excess of light on one side of the line

pressed and the tracing head follows a straight path until the pattern line is intercepted (at less than a 30-deg angle), at which time the electronic-scanning system will follow the line automatically.

A relay in the scanning system switches off the drive-unit motor and energizes the white signal light at the top center of the control panel (Fig. 3) when the end of the pattern line is reached. The gas valves for the torches may also be closed when the relay operates. Because the line tracer stops when proper operation is not possible, either because of a defect on the drawing or because the cut is finished, the operator need not interrupt his other duties as frequently to check the machine's performance.

Components of Line Tracer

The schematic line drawing in Fig. 4 shows the basic components of the electronic line tracer. The tracing head is driven across the pattern table on the tracing drive wheel by the drive-unit motor, a standard arrangement in all tracer-type oxygen shape-cutting machines. A steering signal is developed in the tracing head as it follows the line drawing. This signal is fed through an amplifier to a servo steering motor, which steers the drive wheel through a gear train.

The sensing element providing the steering signal is a photo cell mounted on the tip of a vibrating reed. The reed is vibrated at 60 cps by the current variation in an electromagnet.

The vibration of the scanning photo cell is such that the line on the drawing, as seen by the cell through the tracer's optical system, is crossed virtually at right angles, as shown in Fig. 5*a*. When the line on the drawing is immediately below the center of vibration of the scanning photo cell, the cell receives equal amounts of light near the end of each half cycle of its motion, producing the 120-cps output pulses of constant amplitude in Fig. 5*b*.

When the line on the drawing shifts relative to the center of vibration of the scanning photo cell, two different amounts of light are focused in turn on the cell. The resulting electrical output of the photo cell is shown schematically in Fig. 5*c*, where the cell has shifted to the left so that it is receiving more light from the left side of the line. The larger pulses now occurring at 60 cps are the steering signals, with amplitudes that increase as the excess of light on one side of the tracing line increases.

The proper direction of the steering signal is determined by whether or not the signal is in phase or 180 deg out of phase with the field winding of the servo steering motor (in Fig. 5, the steering signal is in phase with the motor). The steering signal causes the servo motor to drive the gear train through the required angle and in the direction which will close the gap between the line on the drawing and the center of vibration of the photo cell. Because the electronic system is extremely sensitive and its response to change in the relative position of the line is virtually instantaneous, there is no visible lag in following the line.

Welding, an essential process in the building of nuclear-power plants

WELDING QUALIFICATION AND COMPONENT PERFORMANCE

Author discusses the multitude of considerations which are needed to assure usable welded structures

BY W. L. FLEISCHMANN

ABSTRACT. This paper attempts to show that component performance and weldability tests are interrelated and that in the context of component performance weldability tests assume the role of simulated service tests.

Joint welding procedure qualifications have been found to be made under rather closely controlled conditions and many tribulations associated with weld fabrications are due to insufficient attention to details. The conclusion has been reached that weld qualification should include "workmanship" standards. These "workmanship" standards can be an effective tool for quality control on the floor of the fabricating shop so that the nondestructive tests performed on the completed welds can be passed with great assurance.

Introduction

Of the many manufacturing processes, welding has probably the closest relationship to design engineering. It is also probably correct to state that there is no metallurgical process, which might affect the mechanical structure of the material, that is applied so late in the final manufacturing and assembly steps as welding.

Therefore, it is not surprising that the paragraph with which the late H. W. Gillett introduced the chapter "Material Selection"[1] in the *ASME Handbook of Metals Engineering Design*, is applicable to welding design: "Selection of engineering material is a series of compromises; one compromise is that between cost of the finished part and the hazard of its possible failure. The designer of aircraft and the designer of agricultural implements must make quite different balances in his compromise. The hazard of failure takes into account the purpose for which a part is intended, its service conditions and the kind and intensity of stresses set up in that part." This statement is almost identical to the thoughts expressed by the AWS Qualification Task Force. There it states[2] that the basic objective of any welding application is to obtain a weldment which will be adequately serviceable for the purpose for which it was designed and fabricated.

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Table 1

Service loading	*Service temperature*	*Service properties*
A. No significant stress	1. Normal	(*a*) Leak tightness (gas, oil water, etc.)
B. Static	2. High	(*b*) Thermal conductivity
	3. Low	(*c*) Electrical conductivity
C. Fatigue		(*d*) Corrosion
D. Impact		(*e*) Wear
E. Thermal shock		(*f*) Appearance

The enumeration of general factors listed in Table 1 of the Proposal of the AWS Qualification Task Force is again identical to the approach employed in metals engineering for material selection.

For many applications of welding, such as in pressure vessels, the practice has been established that welding procedures and welders be qualified. In so doing, a number of tests has to be performed. But because welding procedure qualifications are not defined in terms other than making certain tests, the significance of welding procedure qualification is not in any way related to the adequacy of the weldment in respect to its application.

To make a weld which meets the specific requirements of an application, a number of separate and distinct problems must be solved.

1. To assure that the weldment meets the operational requirements, it is essential that engineering data are collected. This investigational effort, be it library research or metallurgical and mechanical laboratory work, has to search for those factors which make the weldment in its specific application unique. These engineering tests produce property data on the base metal, weld deposit and welded joint as they relate to the application.

2. The design of the welded joint has to be selected so it will meet the service requirements.

3. The factory has to prove its capability of producing the specified welds. This is done by having welders prove their skill in the welder's qualification and by testing welded joints made by the prescribed joint welding procedures.

4. The production welds made by qualified welders in accordance with the applicable joint welding procedures have to meet the specified quality levels.

This report will review first how service and environmental conditions determine selection of materials and engineering design. Second, it will be postulated that welder's qualification and qualified joint welding procedure do not suffice to assure that sound welds are produced. A third element is needed to assure that details of the welding procedure be followed in fabrication to assure that the welds pass the final nondestructive tests.

The Fracture Problem

From a designer's point of view, the characteristic feature of welded design is the continuity of the welded structure. Failure analysis of welds in such a monolithic structure is difficult because the part and the weldment are, mechanically speaking, one part. Thus, it has to be ascertained whether the cause of failure is associated with the process of welding, including the choice of weld metal, whether the weld was incorrectly designed or whether failure was due to the over-all design, residual stresses or operation of the equipment.

The difficulty of analyzing the failure of a welded structure is examplified by the early emphasis on welding as the cause of the break-up of welded ships. Surely, welding was partially responsible in that many failures started from flaws in the weld and in that, after a crack had formed, this crack could propagate over great distances because of the continuity of the structure. And because in welded design the probability of built-in, designed-in or happenstance stress raisers is great, the attention of the engineering and manufacturing departments must be consistently directed toward correct weld design and sound fabrication procedures.

Only by progress outside the field of welding could new facts be developed about the prevention of brittle failure. Besides the possibility of a change to a more notch-ductile steel which as an optimum could have a metallurgical structure of tempered martensite throughout the section thickness, a better understanding of the meaning of brittle transition temperature to brittle failure of structures was needed. Pellini and Puzak,[3] by their introduction of three significant fracture temperatures (NDT, FTE and FTP), established the basis for rational use of fracture data. These

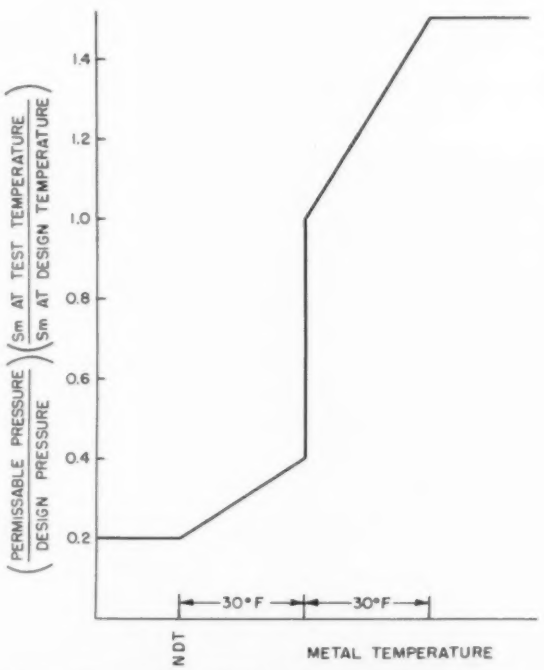

Fig. 1 Pressurization schedule of pressure vessels based on brittle transition temperature

above-mentioned fracture temperatures are defined as follows:

NDT—The temperature below which the steel loses all ability to deform in the presence of a sharp crack (i.e., nil ductility, % elongation = 0).

FTE—The temperature below which brittle fractures will run through elastically loaded material (fracture transition for elastic loading).

FTP—The temperature above which only shear tearing is possible, irrespective of severity of plastic loading (fracture transition for plastic loading).

The concept of the temperature-stress sensitive structural behavior leads to the establishment of a temperature dependent loading schedule of pressure vessels.[4] In such a schedule, pressurization to the design pressure is not allowed to occur until the metal temperature of the metal part with the highest transition temperature has reached a temperature 30° F above its NDT—the hydrostatic test pressure is set at NDT plus 60° F (Fig. 1).

The extent to which a brittle fracture will travel through a structure is not solely a function of the stress distribution and temperature at the fracture but depends also upon the elastic energy stored in the structure. A recent paper[5] shows by some tests that when conditions favorable to a high strain-energy release are present, ductile initiation of the failure is likely to change into a brittle fracture traveling rapidly through a structure. The data were derived from slow notch-bend tests. The less stiffly supported specimens into which the supporting structure fed strain energy had a higher fracture transition temperature than those whose supporting structures were rigid. The author of Reference 5 considered the size effect as related to stored energy and his data (Fig. 2), though plotted on different coordinate, show the same type of behavior as data obtained on material from burst rotor-generator forgings[6] (Fig. 3).

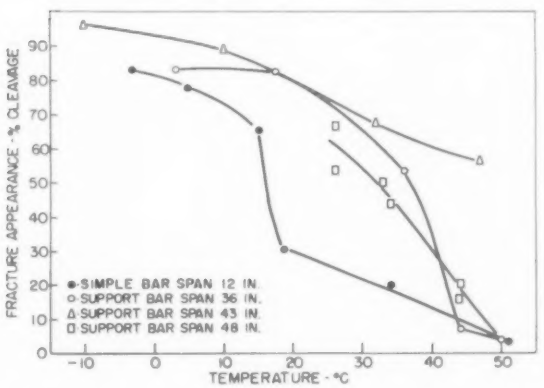
FRACTURE APPEARANCE - % CLEAVAGE
TEMPERATURE - °C
●-SIMPLE BAR SPAN 12 IN.
○-SUPPORT BAR SPAN 36 IN.
Δ-SUPPORT BAR SPAN 43 IN.
□-SUPPORT BAR SPAN 48 IN.

Fig. 2 Increase in transition temperature of carbon steel due to increased stored energy

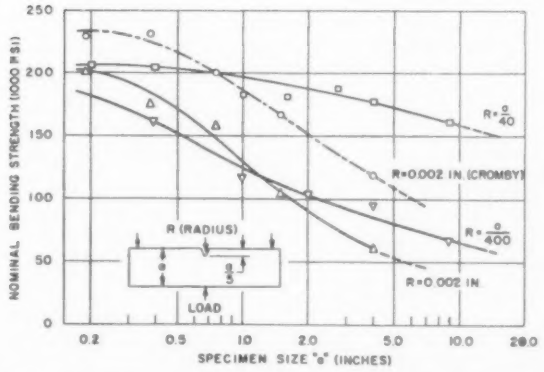

Fig. 3 Apparent size effect on brittle transition temperature

Though the preceding discussion of brittle failure and stored energy is of general engineering concern, and not solely connected with welded construction, it is of specific interest to weldments because:

1. Welded construction lends itself toward monolithic design.
2. Residual stresses are present unless the structure is given a postweld heat treatment for the relief of those locked-up stresses.

In a welded component, the existence of residual stresses which is present as balanced tension and compression stress contributes to the likelihood of failure, provided a crack nucleus is present.

Experience with performance of structures in high-temperature service leads to the conclusion that postweld thermal treatments of welds are an insurance toward longer life of the component. A good illustration of the improved performance of postweld treated weldments is found in Fairchild's paper[7] on eight years' experience with austenitic stainless-steel steam piping.

The author has knowledge of several cases where repair welds in alloy-steel castings used in high-temperature service failed after several months' service. Those welds, after repair and stress relieving, have now given many years' service.

Failures of diesel-engine piston rods in marine service were attributed by Sachs[8] to higher residual stresses present in quenched-and-tempered than in annealed steel forgings.

This emphasis on the importance of residual stresses seems to be appropriate as quenched-and-tempered steels are now considered for pressure-vessel work, and these internal stresses might contribute to early failure under cyclic and corrosive service conditions.

Specific Weld Metallurgical Problems

The application of each weldment brings up the question of the chances of making a sound weld and of its survival in service. To be able to answer these questions, knowledge of the metallurgy of the elements making up the weld have to be obtained. These elements are the weld heat-affected zone and the weld deposit. Considering the weld heat-affected zone as an alloy, it is peculiar because it changes in incremental

fashion from the chemistry of the base metal to the chemistry of the weld deposit.

Looking at the metallurgical structure of the weld heat-affected zone, again it changes in incremental fashion due to the peculiar thermal history, fast heating up to the fusion temperature and rapid cooling. Thus, also the mechanical properties can be assumed to change. They cannot be described in the regular terms because all mechanical-property tests are based on homogeneous material.

The weld deposit can be considered a casting poured on the microscale. Hence, all problems associated with melting, pouring and solidification from gas absorption to shrinkage cracks are contained in the making of a weld deposit.

The Weld Heat-Affected Zone

The changing nature of the weld heat-affected zone to which no definitive properties can be assigned, makes it imperative that each alloy and application have its own testing approach.

The occurrence of chain graphite,[9] found in welded carbon-molybdenum steels after operation at elevated temperature (900° F and above) shows the necessity of considering time-temperature relationships for evaluation of weld heat-affected zones for long-time, high-temperature service.

The experience of the power industry that all weld failures of austenitic steam piping (Type 347) were confined to the weld heat-affected zone,[10] shows the sensitivity of that alloy towards hot cracking. Though the mechanism of the cracking seems to be understood as liquation of grain-boundary phases[11,12] the reason for certain heats to be sensitive and others to be seemingly immune is not understood. There appears to be a certain relationship between the tendency of the base metal to hot cracking and its hot ductility as measured in the RPI "hot ductility test."[13] If the causes for the variations exhibited in the RPI hot ductility test were known, an attempt could be made to write a specification for Type 347 stainless steel which would exhibit consistent hot ductility.

The Weld Deposit

The weld deposit is usually chosen to be of the same type as the base metal, and the engineering properties of the deposit can be determined in the same manner as for cast material. Special consideration, however, must be given to the fact that a welding alloy has to possess good hot ductility to assure freedom from shrink or hot cracking especially when heavy restrained welds have to be made. For this reason, welding alloys must be closely balanced and this balance might, in some cases, be an unbalance as far as the application is concerned. For instance, the ferrite content in an austenitic stainless-steel weld deposit might be undesirable for magnetic and high-temperature work.

Joint Design

Joint design is an important factor which has already to be considered in the conceptical design. A question of whether a blind weld or a weld made from both sides is a good weld cannot be answered without considering the service. In general, good design practice should follow the recommendations made by Dolan:[14]

1. Grinding butt welds flush and smooth.
2. Avoiding lap joints and aligning parts to avoid secondary bending.
3. Providing gradual transitions in joining plates of different thickness.
4. Streamlining fillet joints by elongating fillets or smooth grinding to a gradual transition section.
5. Avoiding high shrinkage stresses by planned sequence of welding.
6. Eliminating undercuts, bracket misalignments or openings at location of high stress.
7. To minimize failure due to temperature cycling, through-welds should be used to transfer heat as uniformly as possible and to reduce stress conentrations.

The recommended welding connections for pressure vessels of the International Institute for Welding[15] are a good illustration of the application of those general design recommendations.

Weld failures which are caused by violation of the above principles are shown in Figs. 4 and 5. Figure 4 shows the failure of a steam lead[16] when the welded joint was left as a thickness discontinuity between the pipe and valve. Figure 5 shows three cases where cracks started from locations which can be considered stress concentrations. The loading was exclusively thermal cycling.[17]

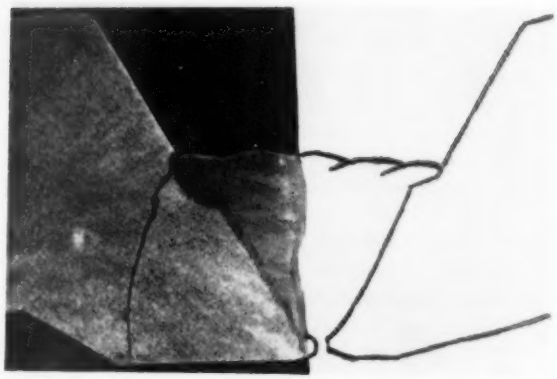

Fig. 4 Failure of steam lead due to incorrectly welded butt joint

Attention to good design details is not a typical requirement for welded construction; it is applicable to equipment in general. Its omission from this review would, however, have excluded an essential feature of good fabrication.

Weld Quality

Weld quality is a relative term, because the definition

of what constitutes a serviceable weld depends upon the application of the weldment.

Irrespective of the required quality level, however, the shop's capability of producing the specified weld has to be determined. In the pressure-vessel industry this is done by two tests.

The produceability of a sound weld is established in the "Joint Welding Procedure Qualification." The weldment has to meet certain visual and radiographic standards. The mechanical properties of the weldment and weld deposit are determined at room temperature to meet minimum specified properties arrived from the engineering tests.

The welder's proficiency is established by the so-called welder's qualification. Welds produced for that purpose are examined by nondestructive test methods and samples of the weldment have to meet certain ductility and strength requirements.

Cases of failure in meeting the required qualification tests for the established code materials are rare, because the necessary background for making welds in those materials is generally available. Their value is limited to the extent to which the fabricating shop adheres to the required exacting conditions laid down in the procedure qualifications.

Weld Quality Control

Without doubt, any engineer associated with welding in design or fabrication can enumerate examples where better communications between engineering and shop inclusive inspection could have avoided rework in the shop or actual failure of the equipment in the field.

Who has not heard of trouble associated with fabrication defects caused by poor fitup or failure due to dirty welds and undercutting, even though the joint welding procedure was qualified and the welder had passed his qualification tests?

Recognition of the limited significance of such welding qualifications is found in the already mentioned AWS Task Force.

The use of "workmanship" or "appearance" standard is suggested as amplification of the procedure qualification.

This standard[18] is the weldment in question with successive layers made visible by welding the sample by the back-step method. Figure 6, taken from the *Inspection Handbook for Manual Metal-Arc Welding*,[18] shows schematic workmanship standards.

These appearance standards can be effective means of quality control because they permit visual step-by-step observation of product quality. Though these "standards" were written up in the *Manual Arc Inspection Handbook*, the identical principle is applicable to any kind of joining procedure and, the more mechanized the process is, the more important it is to have agreed-upon visual aids available to permit control.

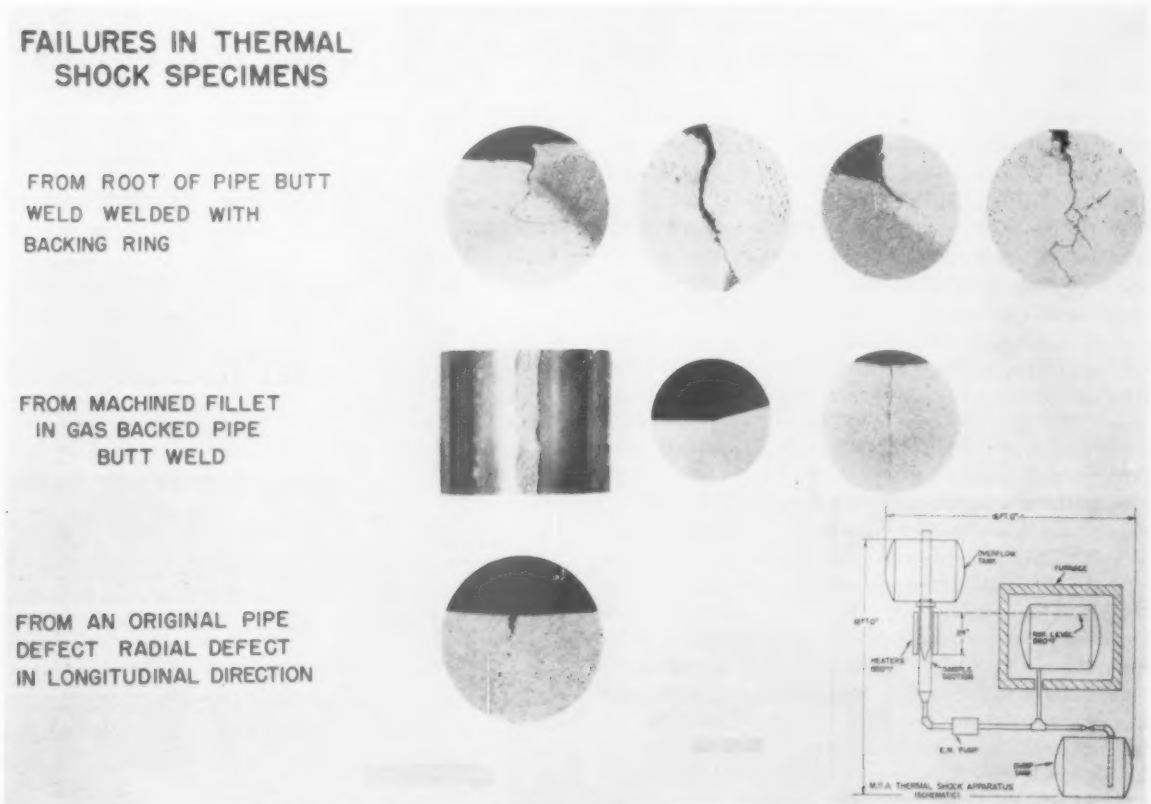
FAILURES IN THERMAL SHOCK SPECIMENS
FROM ROOT OF PIPE BUTT WELD WELDED WITH BACKING RING
FROM MACHINED FILLET IN GAS BACKED PIPE BUTT WELD
FROM AN ORIGINAL PIPE DEFECT RADIAL DEFECT IN LONGITUDINAL DIRECTION

Fig. 5 Discontinuities acting as "starters" for fatigue cracks

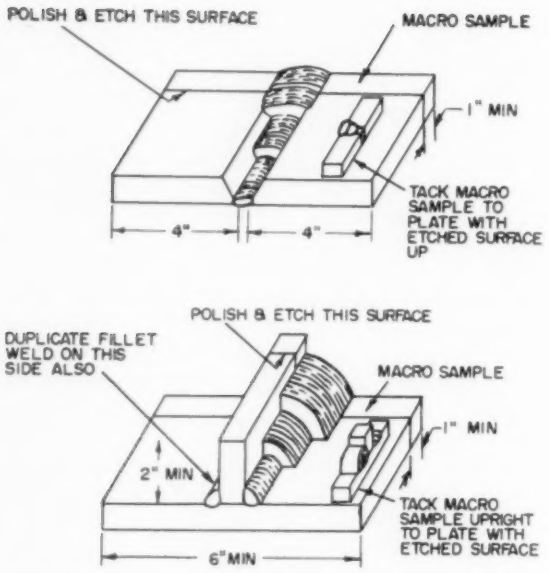

Fig. 6 Schematic "workmanship" standard

The final nondestructive test establishes only the soundness of the weld, though the weld quality is dependent upon many other factors, which may not result in cracks, porosity and the presence of slag.

The inclusion of such a "workmanship" standard in the Joint Welding Procedure Qualification will give the shop a good measuring stick and engineering a good record of the capability of the designed weld produced by the specific process.

Summary

The discussion illustrated, with examples, the multitude of considerations which is needed to assure usable welded structures.

1. It was pointed out that welding design has to consider the application by attention to weld details.

2. It was also shown that brittle failure and the presence of residual stresses need attention in welded design to a greater degree than with other structures because of the stiffness of welded structures and the possible presence of "crack starters."

3. The complexity of metallurgical phenomena associated with welding requires detail studies patterned upon the application of the weld. One might look at these tests as necessary to establish weldability defined as "The capacity of a metal to be welded under the fabrication conditions imposed into a specific, suitably designed structure and to perform satisfactorily in the intended service."[19] In a sense, these experiments are simulated service tests because the material in the form of weldment, heat-affected zone or weld deposit is tested in some relation to the making or the later service of the weld. This type of testing establishing the suitability of the weldment, usually isolates certain variables deliberately to determine specific responses of the weldment to environmental conditions. Such tests conducted for the purpose of obtaining engineering knowledge will establish the suitability of the weld design, the process and the correctness of the material selection.

4. It has been recognized that Joint Welding Procedure Qualification and Welder's Qualification are important steps to obtain required weld quality. The only too-frequent welding troubles, however, point out that closer control on the manufacturing floor is needed.

The "workmanship" sample which makes available a means of comparison for every step in the welding process should be utilized for quality control during the making of the production welds.

It is hoped that this résumé helps to clarify the relationships of the various tests necessary to produce welded equipment giving trouble-free service.

It is also hoped that the two qualification tests will be expanded or so conducted that they give to quality control intermediate check points or standards so fewer welding troubles are experienced.

Acknowledgment

It is obvious that many thoughts expressed in this paper are due to the fact that the author has had the privilege of association with many qualified engineers employed at the Knolls Atomic Power Laboratory and other engineers in this field.

Special thanks are due to R. W. Clark, consultant, General Engineering Laboratory, General Electric Co. He suggested that the means to better shop control vaguely described in the final draft were "workmanship samples" and he encouraged the author to emphasize the important function of this "workmanship sample" in the quality control of welding.

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CUPRO-NICKEL WELDED WITH ALUMINUM BRONZE

Paper by V. Abaravich has been published in the March 1958 issue of The Welding Journal, 37, 220–224.

DISCUSSION BY J. IMPERATI

The statements made in this paper must be the result of misinformation regarding the fabrication and welding of the cupro-nickels. Manufacturing controls needed to produce cupro-nickels for trouble-free fabrication have been known and used for years. These measures have been so effective that millions of pounds of these alloys have gone into service on Naval vessels alone as piping and pressure-vessel components. It is hard to reconcile this fact with the assertion that "difficulties have consistently occurred in the fabrication of this alloy due to its hot-short characteristics."

The proposal to use ECuAlA2 electrodes is apparently justified by an inference that weld cracking is common when copper-nickel filler metals are employed. However, we must remind the author again of the immense quantities of these alloys being used, plus the fact that most are being welded without difficulty using the excellent copper-nickel electrodes and filler metals that are available. To our knowledge there are at least two brands of covered electrodes which comply with Bureau of Ships Specification MIL E-19323. These, along with a special copper-nickel filler metal for inert-gas arc welding, are regularly used for welding cupro-nickel piping and condenser water boxes on Naval vessels.

Copper-aluminum alloys are anodic to cupro-nickel, and it might be expected that welds made with copper-aluminum filler metals may be preferentially attacked in certain media. Since most of the cupro-nickels made go into salt-water service, the question of corrosion resistance cannot be brushed off as lightly as this paper does, and since suitable welding filler metals of compatible alloys are available, there can be no justification for accepting the risk of corrosion attack on welds made with copper-aluminum filler metals. It would be very enlightening if the author could describe the applications where difficulties have "consistently occurred." It would also help to know whether, in these cases, assistance had been sought from the suppliers of the well-known and approved copper-nickel welding filler metals.

J. Imperati is welding engineer for the American Brass Co., Waterbury, Conn.

DISCUSSION BY F. L. LAQUE

In his paper Mr. Abaravich based his interest in the use of aluminum bronze for welding the 90–10 cupro-nickel alloy on assertions to the effect that cupro-nickel alloys are characteristically hot short. No evidence in support of these assertions or assumptions was presented. Our extensive experience with the welding of cupro-nickel alloys and other opportunities to observe behavior at welding temperatures have not indicated any characteristic hot shortness. We, and many others, have welded large amounts of the alloys satisfactorily with cupro-nickel electrodes having the same basic composition, as well as with electrodes of higher nickel content as covered, for example, by the requirements of Specification MIL-E-19323 (Ships). We have established by test and experience that these welds have satisfactory mechanical and corrosion-resisting properties.

Under the circumstances, while we welcome the news that aluminum bronze can also be used to produce mechanically satisfactory welded joints, we must take exception to the statements that such use of aluminum-bronze electrodes is made necessary, or even desirable, by a deficiency of the cupro-nickel alloy in the form of hot shortness.

Since the aluminum-bronze weld deposits would be expected to be less noble than the cupro-nickel alloys and basically inferior in resisting corrosion and, especially, erosion by salt water, we would favor the use of cupro-nickel welding electrodes for cupro-nickel alloys, thereby providing the best combination of mechanical and corrosion-resisting properties for the critical applications in which these alloys are most generally used.

F. L. LaQue is Vice-President, Development and Research Division of The International Nickel Co., Inc.

DISCUSSION BY L. H. HAWTHORNE

It seems apparent that the author may have encountered an isolated case where a fabricator perhaps unfamiliar with the characteristics of the cupro-nickel alloys has encountered difficulties. It seems equally apparent that the author has drawn inaccurate conclusions and has accepted this isolated case as the rule rather than the exception.

The 70–30 cupro-nickel alloy has been used extensively by the Navy on all major combat vessels for sea water applications since the early 1930's. This material is readily weldable using commercially available covered electrodes of similar composition. In general, these electrodes can be used in all positions with the same techniques as those employed in welding steel. More recently, a satisfactory filler metal designed for use with the gas-shielded arc processes has been made available by a major manufacturer of nickel-alloy electrodes. This material, although it is basically of the 70–30 composition, is satisfactory for welding all varieties of cupro-nickel.

The author, indicating in his opening paragraph that the 90–10 cupro-nickel was developed and introduced to replace the 70–30 alloy, is incorrect. Corrosion resistance of the 90–10 cupro-nickel alloy is equal to and in some cases superior to the 70–30 alloy for some applications. In these applications it is being used extensively to replace the 70–30 alloy because of desire to conserve nickel and reduce cost.

However, in those cases where the corrosion resistance of the 70–30 cupro-nickel is obviously superior, no attempt has been made to replace this material with the 90/10 alloy.

Admittedly, the 90–10 alloy, the thermal conductivity of which is given as 27 (Btu/sq ft/ft/hr/° F @ 68° F) as compared to 17 for the 70–30 cupro-nickel alloy, makes welding somewhat more difficult with covered electrodes primarily because of greater heat requirements. No trouble has been experienced by competent operators in the welding of this material. In certain cases, operators have experienced difficulty in producing a satisfactory side bend conforming to Navy test requirements due to undercutting on the vertical side of the joint with such undercutting inadequately fused out on subsequent passes. In every case, this difficulty has been corrected with a demonstration of proper techniques.

It should, however, be noted that since the introduction of the 70–30 cupro-nickel alloy widely used for gas-shielded arc welding, the use of metal-arc welding on both of these alloys has been decreasing constantly.

Furthermore, it is well-known that the welding of cupro-nickel to steel has in the past presented serious problems due to the inability of welds made with covered cupro-nickel electrodes which are available to tolerate iron pick-up Therefore, in those cases where it was necessary to weld cupro-nickel to steel, it was advantageous to overlay the steel side of the joint with a modified Monel alloy prior to the execution of the final weld. This eliminated microcracking at the steel interface. This difficulty, however, does not in any way indicate that the cupro-nickel alloys are hot-short.

The use of the modified 70–30 cupro-nickel filler metal and either of the gas-shielded arc methods of welding has eliminated the need for an overlay on the steel side of such a joint. This filler metal can tolerate the dilution of relatively large amounts of iron without deleterious effects on either strength or ductility. Moreover, this filler metal does not, under any condition of stress, exhibit hot-short characteristics.

Figure 1 herewith is a photograph taken from a paper entitled "Welding the Cupro-Nickels by the Inert-

L. H. Hawthorne is manager of the Welding Service Research Department of Revere Copper and Brass Inc.

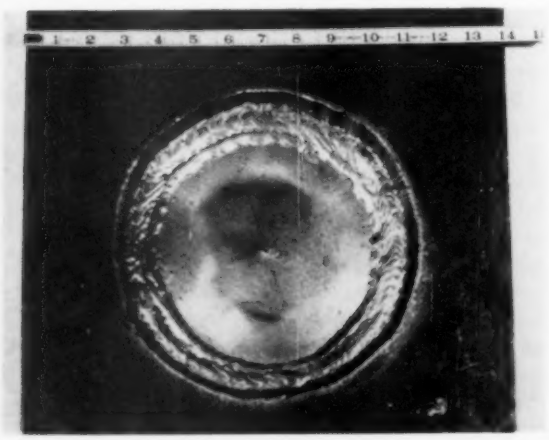


Fig. 1 Restrained weld between $^1/_2$- x 7-in. diam. 90-10 cupro-nickel plate and $1^5/_8$- x 14- x 14-in. steel

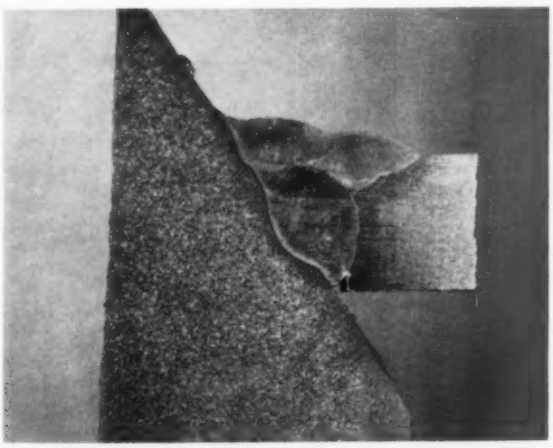


Fig. 2 Cross section of weld shown in Fig. 1 prior to the application of a reverse pass. Magnification X 2

Gas-Shielded Arc Process" presented by R. F. Burth and L. H. Hawthorne at the 1956 AWS National Spring Meeting in Buffalo, N. Y. This photograph shows a 1/2- x 7-in. diam 90/10 cupro-nickel plate welded into a 1 5/8- x 14- x 14-in. steel plate. This most assuredly is a highly stressed joint. Angular joint preparation was used only on the steel side of this joint with the edge of the round cupro-nickel insert left square. This weld was made in four passes employing the gas-shielded metal-arc process with the reverse side chipped out and rewelded.

Figure 2 herewith is a cross section of this joint showing the depth of each pass and the sequence of welding. In this photomacrograph the reverse pass had not yet been made so that contour and depth of the first pass would be readily visible. It is apparent in this photomacrograph that considerable iron dilution would take place in the application of the first pass; it is also apparent that this pass does not approach the stringer-bead technique and high rate of travel claimed to be necessary in the paper under discussion. No cracking is evident. It is believed that a restrained joint of this type will develop stresses of much higher magnitude than the clamping provided for the execution of welds made in connection with the preparation of the material for this paper. We do not believe that clamping alone will provide sufficient rigidity or restraint on the test plates to develop stresses high enough to cause failure in a welded joint employing any suitable combination of materials.

While it is well known that the aluminum-bronze filler metal referred to in this paper has excellent hot ductility and in no case would a fabricator expect to encounter hot-short cracking in its use either in this application or any other where it was suitably employed, this does in no way modify the fact that the precept on which this paper was written, i.e., that cupro-nickel is hot-short, is incorrect.

Hence, there is no justification for the recommendation that aluminum bronze be used for welding either cupro-nickel to cupro-nickel or cupro-nickel to steel other than one of immediate availability.

AUTHOR'S CLOSURE

Perhaps the author of the article "Cupro-Nickel Welded with Aluminum Bronze" may have been a bit presumptuous in assuming that the difficulties encountered in the fabrication of the cupro-nickels were of a general nature. However, from inquiries received directly requesting recommendations for the successful joining of the cupro-nickels, plus published references regarding the difficulties encountered, Ampco engineers do believe that enough trouble does exist to warrant continued research work relative to the subject.

Although the literature pertaining to the subject is not extensive, may we refer to the following reference excerpts:

1. The "Tentative Specifications for Copper and Copper-Alloy Welding Electrodes" ASTM Designation B225–53T AWS Designation A5.6–53T, pages 10 and 11, states: "It is advisable to plan the work so that welding is done without too many interruptions to avoid cracks that tend to occur when the arc is broken. These cracks are attributed to the hot-short characteristics of the material."

2. The WELDING HANDBOOK, 1950 Edition, chapter 34, page 755 states: "Also, these alloys are hot-short, therefore, no preheat should be used and interpass temperatures should not exceed 150° F." The following paragraph reads: "Peening moderately with a flat tool is desirable to improve mechanical properties of the deposit and reduce stresses in order to avoid cracking."

3. "Welding the Cupro-Nickels by the Inert-Gas-Shielded Arc Process" by Hawthorne and Burth states: "Heretofore, the older 70–30 cupro-nickel alloy has been welded quite satisfactorily by the metal-arc process, but the new 90–10 cupro-nickel alloy which has been gaining in usage has presented some problems to fabricators because of the relatively higher thermal conductivity."

4. *Sumitomo Metals*, Volume 9, No. 4, October 1957: "On the Inert-Gas Shielded Tungsten-Arc Welding of 90–10 Cupro-Nickel" by Keuchi Mizuno states: "The sound welds having good mechanical properties were obtained by using filler wires of the same compositions with base plates in thinner sections, but good structure welds were not obtained in thicker plates."

5. *Welding of Non-Ferrous Metals*, Volume III, edited by E. Fuchs and H. Bradley, on page 52 states under the subheading of cupro-nickels: "Metal-arc welding with some of these alloys may give rise to difficulties due to cracking in the parent metal if this is not in the fully annealed state or if the joints are welded under any degree of restraint."

6. Reprint from *Steel*, 1944 "Metallic Arc Welding Electrodes" by Harold Lawrence, chapter 13, page 82 states: "Group E, Cupro-Nickel; most of the welding data given in the preceding article in the discussion of Monel metal welding will apply to the welding of cupro-nickel. There are four sources of trouble that will be encountered: . . .Point 3. Tendency towards hot shortness."

The general observation that the weldability of the cupro-nickels must be satisfactory because millions of pounds of the alloy have been fabricated by welding in the past can hardly be construed as proof any more than one can say that copper, cast iron, silicon bronze and Navy G alloy are readily weldable, although thousands of pounds of these alloys are fabricated annually using

special procedures and techniques.

In the author's opinion, it is no more inconsistent with good welding practice to use aluminum-bronze electrodes to join 90–10 cupro-nickel than it is to recommend the use of 70–30 cupro-nickel or Monel electrodes. We do agree, however, that corrosion resistance of any welded area is an important factor.

The tests conducted by Ampco Metal, Inc., resulting in the presentation of the paper using ECuAlA2 electrodes and the inert-gas consumable-electrode method for fabricating 90–10 cupro-nickel, were made at the insistence of a rather large fabricator because welds made with ECuNi were consistently cracking in production. The plate supplier had been consulted relative to the job and had failed to provide a solution. The fabricator conducted tests with ECuAlA2 and found that full joints could be made in the 90–10 alloy without cracking and that cracked joints previously made with ECuNi could be successfully repaired by this method. They requested that Ampco engineers conduct confirming tests using trimmings from plates which had given them trouble in fabrication. These tests were those released in the paper. Since the plate composition fell within published manufacturing and specification limits, it was assumed to be representative of the quality supplied for fabrication purposes.

In addition to the fabricator for whom these confirming tests were conducted, Ampco Metal, Inc. was approached by another fabricator of the same type of weldment having the same difficulties. From our experience, ECuAlA2 electrodes were recommended.

Within recent months, Ampco was also approached by a large shipbuilder relative to the difficulties encountered in the welding of 90–10 cupro-nickel piping to itself and to steel aboard ship. Their interest lay in the area of help in securing American Bureau of Shipping approval for the use of ECuAlA2 electrodes for these joining applications since their tests had indicated a considerable improvement over the use of ECuNi to join 90–10, and Monel electrodes to join 90–10 to steel. We do not feel at liberty to disclose the source of these inquiries for publication purposes.

With reference to corrosion resistance of the joints made in 90–10 cupro-nickel with ECuAlA2 electrodes, it was stated in the paper that no tests had been conducted. It is realized that it is very difficult to predict actual performance in view of the admixture of filler and plate in the deposit. Specimens of the joints can be provided to Messrs. LaQue, Hawthorne and Imperati for test purposes if they have not already conducted such tests in support of their criticism.

If they have conducted such tests we would appreciate receiving the test data, since it is not the intent of the paper or the conclusions reached to mislead anyone. Further work on the problem was contemplated, which included corrosion testing. In the meantime, it was assumed that a fabricator using the proposed method of joining would conduct his own corrosion tests prior to actual production. This is normal procedure when one is producing corrosion-resistant weldments.

It is sincerely hoped that this exchange of correspondence regarding the joining of the cupro-nickel alloys will in no way affect the excellent relations maintained between Ampco Metal, Inc. and the producers of copper-nickel alloys, for we do have a high regard for these alloys and we have every reason to believe they have the same feeling with regard to the Ampco Metals. We did not realize that the presentation of the paper would develop into a controversial issue which we would prefer to avoid.

INSTRUCTIONS

FOR

PROSPECTIVE AUTHORS

Authors who plan to submit papers for publication in THE WELDING JOURNAL are invited to send for a free copy of the booklet "Instructions and Suggestions for Authors." All requests should be addressed to Editor, THE WELDING JOURNAL, American Welding Society, 33 W. 39th St., New York 18, N. Y.

THE ATOMIUM DRAMATIZES WELDING

BY CLARENCE E. JACKSON

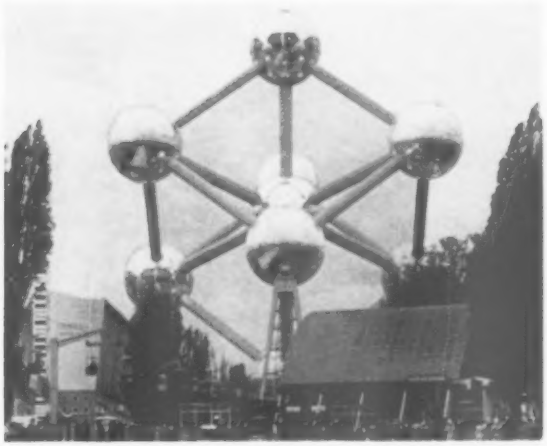


Fig. 1 The Atomium, designed and built for the Brussels Universal and International Exhibition 1958, by the Belgian Metal Industries

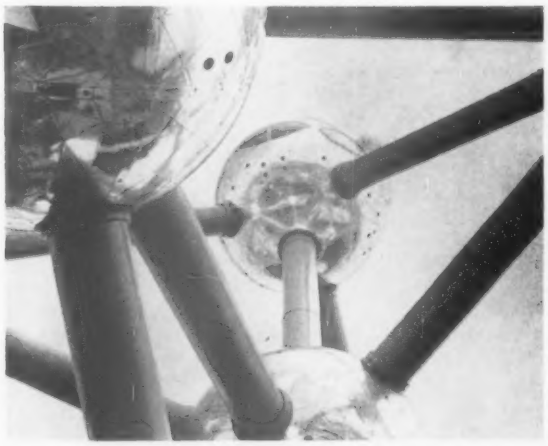


Fig. 2 Spheres 59 ft in diameter and tubes 9.8 ft in diameter show an intricate pattern

Europe is generally very cognizant of the ease of application and economy of welding. It is not surprising to find that the 1958 Brussels Universal and International Exhibition is a welded extravaganza. Welding is evident everywhere. The welded handrails, lamp-posts, buildings, archways, statuary, however, are all dwarfed by the boldly designed and welded Atomium (Figs. 1–12).

The Atomium, a 2300-ton metal structure with a height of 102 m or 334.6 ft, is approximately 150 billion times magnification of a single unit of a body-centered cubic structure of alpha iron. The basic structure is constructed of steel and the skin of the nine spheres is

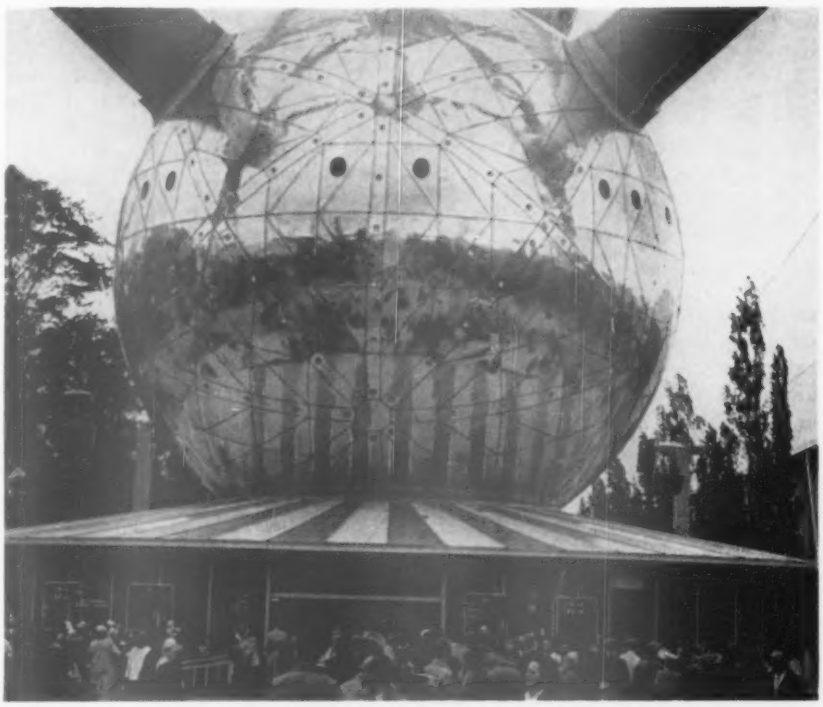


Fig. 3 Lower sphere with entrance to elevator and high-speed escalators

Clarence E. Jackson is staff engineer at the Linde Co., Newark, N. J.

Fig. 4 Inside of welded tube showing high-speed escalator

Fig. 6 View from top sphere of area below Atomium

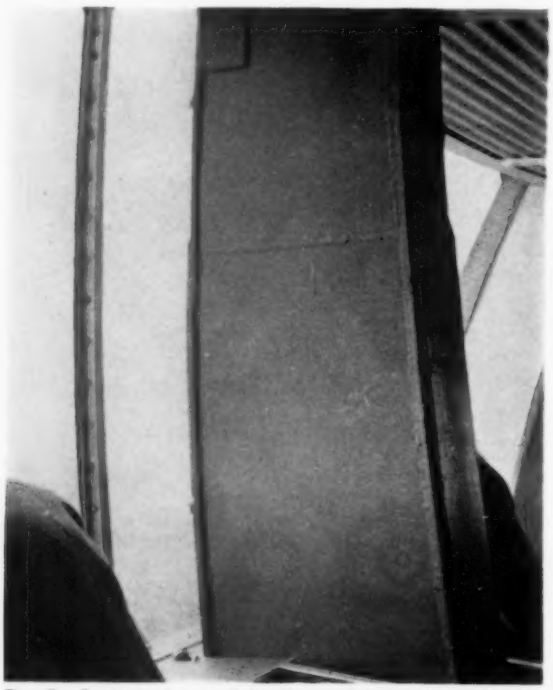


Fig. 5 Section of one of the 5-ton arches making the steel framework of top sphere. The 12 arches of each sphere are made up entirely of a welded box using 12 mm (.47 in.) thick steel

Fig. 7 Three 100 ton welded "bipods" insure stability

made of aluminum. The nine spheres, each 59 ft in diam, are tied together on the sides by 95.1-ft long welded steel tubes 9.8 ft in diam; the diagonal tubes are 75.4 ft long and of 10.8 ft diam (Fig. 2). Stairways and high-speed escalators provide transportation for the visitors (Figs. 3 and 4). A high-speed elevator travels from ground level to the top sphere (Fig. 5) at 5 m per sec (16.4 ft/sec). It can carry 22 visitors to the top in 23 sec.

The restaurant in the upper half of the top sphere can seat 140 persons, and the viewing deck just below can accommodate 250 persons (Fig. 6). Seven of the spheres contain exhibits illustrating the peaceful uses of atomic energy.

Stability of the structure is insured by three pylons called "bipods" (Fig. 7). Each bipod weighs over 100 tons and is made up of two enormous 118-ft long triangular box spars welded by the covered electrode and submerged-arc processes. A rigid crossbar (Fig. 8) links the two spars and is assembled on the site by bolted joints. The foot of the welded bipod structure (Fig. 9) rests on a reinforced concrete sleeper anchored to 24 piles driven to a depth of 57 ft.

The central tube of the Atomium, 10.8 ft in diam, is 348 ft long and made up of cylindrical steel tubular sections of 12 mm (0.47 in.) thickness up to a height of 197 ft and of 6 mm (0.24 in.) thickness from this level to the top. The steel plates, which are formed and welded into a tube, are reinforced internally, first by 12 high-grade steel angle bars, 7.87 in. × 7.87 in., and secondly by longitudinal and transverse stiffeners which prevent any buckling of the outer casing (Fig. 10). This central column is highly resistant to bending and compression stresses. The 348-ft high mast is made up of several sections, the lengths of which vary from 10 to 39 ft. The circular space within is entirely occupied by the lift, its guide-rails and counterweights. The base of

Fig. 8 Welded crossbar links spars of "bipods"

Fig. 9 Foot of welded "bipod" structure

the mast is 10 ft below ground level. The central mast weighs approximately 1.81 tons per yard in the bottom half and 1.35 tons per yard from the middle of the central sphere to the top.

The other linking tubes between spheres differ structurally from the central mast; the longitudinal angle bars are lighter, the outer shell is only 6 mm (0.24 in.) thick and the weight of these tubes is only 0.9 tons per yard. All the tubes linking the outer spheres are 9.84 ft in diam, while the diagonal ones, i.e., those linking the outer spheres with the central one, are 10.82 ft in diam. The reason for this difference is that an attempt was made to reduce the tube diameters as much as possible for esthetic reasons. When these were steeply inclined, as is the case for the outer tubes, their vertical section, with a 9.84 ft diam, is sufficient for passage, even in the case of the tube containing an escalator.

There were very few similar constructions from which experience could be drawn for the covering of the spheres of the Atomium. Previous experience with riveted skins was not sufficiently rainproof. In order to arrive at an esthetic solution, the surface of the Atomium spheres was divided into 48 spherical triangles by nine great circles, these great circles being 16-in. wide ribbon sheets (Fig. 11) The congruent spherical triangles were further divided into smaller

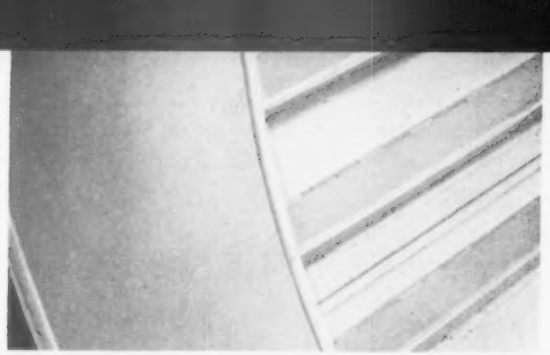


Fig. 10 The welded tubes are attached to the spheres using a heavy collar joined by the submerged-arc welding process

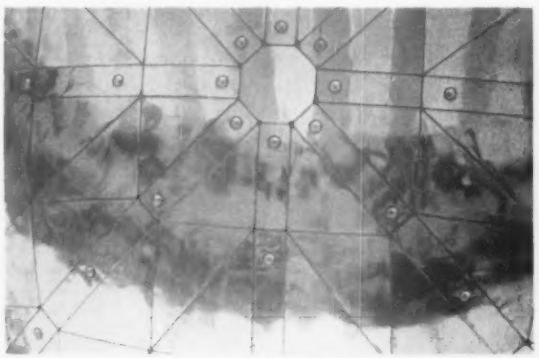


Fig. 11 The surface of the Atomium is comprised of highly polished aluminum cladding which gives the effect of a mirror finish

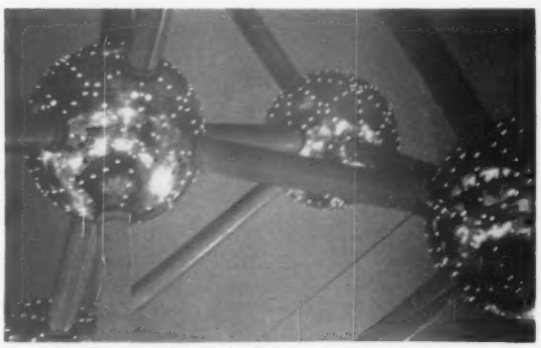


Fig. 12 Spectacular night lighting

spherical triangles in order that the available sheets of 1.2-mm (0.047-in.) thick aluminum clad could be used. The edges of each panel were mounted on a special welded frame; all these panels were bolted together from the inside and their intersection made rainproof by a plastic joint and a second one in rubber. In certain of the spheres, large plexiglass observation windows were put in place of the aluminum panels. Lighting at night (Fig. 12) gives the effect of rotation of the lamps which are spaced at 5 ft and are switched on and off successively.

The Atomium was designed and built for the Brussels Universal and International Exhibition 1958 by the Belgian Metal Industries. The erection of the Atomium was begun early in 1957, and was completed in March 1958.

THE ACETYLENE FLAME IN THE PIPING INDUSTRY

BY H. A. SOSNIN

Over a period of a hundred years, or so, a very large part of all the pipe used in conveying fluids has been threaded. Also, there has been a comparatively small amount of pipe joined by other mechanical methods, such as caulking and compressed gaskets, or packing.

A little over fifty years ago, when acetylene and oxygen became available for commercial and industrial torches, such as welding equipment, the piping picture began to change. That change has continued, and is now accelerating.

The change is to pipe joints that use an acetylene and air or acetylene and oxygen flame.

There are excellent reasons for this change, and the reasons are best seen and understood by looking at some illustrations showing cross sections of joints for 3-in. nominal pipe size.

Figure 1 is a drawing of a typical caulked joint. This is probably the oldest method of joining pipe (with some variations, over the years). Caulked joints are the most used methods of joining cast-iron pipe. This type of piping is used for drainage, water distribution and gas distribution. It is usually buried under ground. At the present time, it is not nearly as popular for even these three uses as it once was.

Figure 2 is a drawing of a compression type joint. This joint is used on cast iron, steel and transite pipe. It is used for comparatively low pressures and temperatures, with plain-end pipe. Its commonest service is in water and gas distribution. It too, is used less than it once was.

Figure 3 is a drawing of a threaded joint. It is used on steel or wrought-iron pipe, or any other material that is cheap enough to be made with much heavier than required walls. It is used especially in small sizes, and in many typical installations. It is the commonest pipe joint used today (in both senses of the word). Its days are numbered, because of its lack of economy and efficiency.

These are the three pipe joints which have been used for years but are being replaced by heated, or metallurgical, joints. Now here are the three joints which are replacing them.

Figure 4 illustrates a soldered joint made with 50-50 solder and an air-acetylene flame. It is used almost entirely on copper and brass pipe or water tube. This material and joint have replaced, almost completely, the threaded pipe in hot and cold-water systems

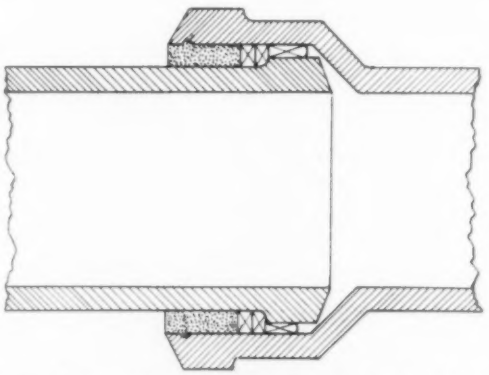


Fig. 1 Cross section of a typical caulked joint, the most-used method of joining cast-iron pipe

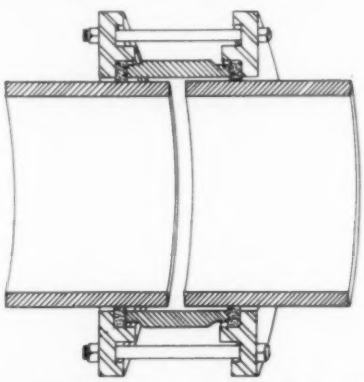


Fig. 2 Cross section of a compression-type joint used on cast-iron, steel and transite pipe

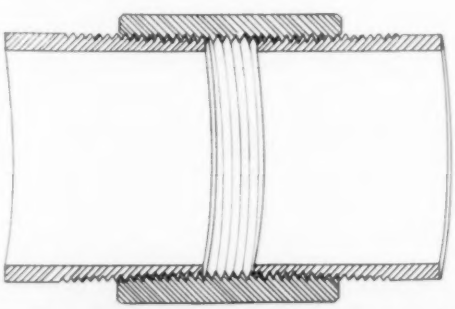


Fig. 3 Cross section of a threaded joint used on steel or wrought-iron pipe

H. A. Sosnin is a special representative for Tube Turns at Louisville, Ky.

Paper presented at 1958 Annual Convention, International Acetylene Association, Philadelphia, Pa., March 19-21, 1958.

Table 1—Comparative Pipe Wall Thickness , In.

Nom. size	*Sch. 40 pipe wall*	*Depth of thread*	*Effective pipe wall*
2 1/2	0.203	0.09850	0.105
2	0.154	0.06957	0.085
1 1/2	0.145	0.06957	0.076
1 1/4	0.140	0.06957	0.071
1	0.133	0.06957	0.064
3/4	0.113	0.05714	0.056
1/2	0.109	0.05714	0.052

Table 2—Comparative Pipe Wall Thickness , In.

Nom. size	*Sch. 40*	*Sch. 80*	*Sch. 80 threaded*
2 1/2	0.203	0.276	0.178
2	0.154	0.218	0.149
1 1/2	0.145	0.200	0.131
1 1/4	0.140	0.191	0.122
1	0.133	0.179	0.110
3/4	0.113	0.154	0.097
1/2	0.109	0.147	0.090

(plumbing). It is strongly competitive with threaded pipe for domestic heating, and with threaded-and-calked joints for domestic drainage.

Figure 5 shows the brazed joint, made with capillary brazing alloys and the oxyacetylene flame. The brazed joint is used mostly on copper and brass pipe and on tubing for plumbing, heating, air-conditioning and industrial piping. It is becoming more popular, too, for use with steel, wrought iron and stainless steel.

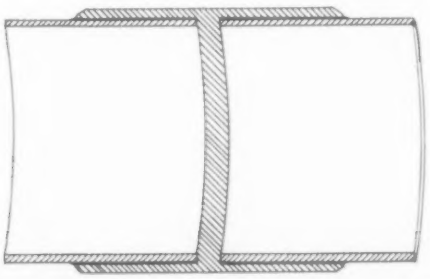


Fig. 4 Cross section of soldered joint made with 50-50 solder and an acetylene-and-air flame, used almost entirely on copper and brass pipe or water tube

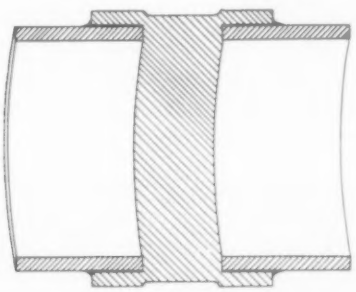


Fig. 5 Cross section of brazed joint made with capillary brazing alloys and the oxyacetylene flame

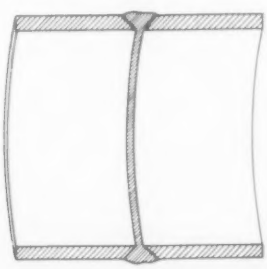


Fig. 6 Cross section of welded joint used for nearly all critical pipe

Figure 6 is the welded joint. This is used for nearly all critical pipe; that is, pipe that is used at high pressure, very high or very low temperature, or pipe that is highly stressed for some other reason. The oxyacetylene flame, with filler metal to suit the particular requirements of the base metal, is especially economical and efficient for joining the small sizes of critical pipe.

The oxyacetylene flame is also economical and efficient for joining small, noncritical pipe. This is pipe used for a myriad of services such as heating, air conditioning, compressed air, natural gas, vacuum and many others. This is the pipe that accounts for about 60% of all pipe used in the United States, if measured in lineal feet.

Since threaded joints comprise a very high percentage of mechanically joined pipe, and are the ones which compete most with the joints requiring a heating flame, let us compare the threaded and heated joints.

Table 1 compares the wall thickness of Schedule 40 (standard) I.P.S. pipe and the depth of thread, at the root. This shows the fundamental weakness of the joint and the wastefulness of this method of joining. Oxyacetylene welding, soldering or brazing would give a strength of piping connections greater than obtained with the next heavier wall thickness threaded.

Table 2 shows the advantage of Schedule 40 pipe welded, over Schedule 80 pipe threaded.

Conversely stated, we could lighten the pipe and fitting wall by 50%, or more, and still have a better piping system, if we made all our joints by welding, brazing or soldering. We should not buy twice as much pipe as we need, then cut off half of it, and throw it away. We should not handle twice as much weight as necessary. We should not waste either time or materials.

Threading pipe is no more advantageous than buying ten tires for one car, then throwing five of them away. If you need only four for the wheels and one for a spare, buy only five. If you need a pipe wall of only 0.064 in 1-in. pipe, why buy 0.133 wall, then cut off half and scrap it?

Further, this is an age when we are lessening physical effort on the part of the mechanic or productive worker. Welding, soldering or brazing require higher skill, but little physical effort, as compared to threading and tightening with wrenches.

PRECISION PLUS

Mechanized precision gas-shielded tungsten-arc welding improves quality, increases production and eliminates machining

BY JOHN J. VIEW AND CHARLES W. PFLEIGER

Partlow Corp., New Hartford, N. Y., manufactures mercury-actuated industrial temperature controls. Instruments cover the entire range from −30 to 1100°F and are used to control heat in a wide variety of applications: industrial ovens and driers, food-process equipment, automatic type-setting machinery, heater-treaters in oil fields, plating tanks, kilns, cotton gins, refrigeration equipment, plastics machinery, tractor trailers and railroad cars.

One of the most exacting facets of this instrument manufacture is the welding of the basic mercury bulb and element. Each instrument is operated by the expansion and contraction of the mercury in a steel bulb. The bulb is attached through a capillary tube to the element head. Inside the element head, the mercury expands or contracts against a very sensitive diaphragm. The movement of this diaphragm is transmitted to a metal plunger which, in turn, activates a series of levers which opens and closes switches, moves dials or operates recorder pins. This movement of the plunger is highly predictable and can readily be translated into degrees on a dial.

The welding of the basic instrument element (bulb, capillary and element head) into one integral part has been accomplished by teams of two men: an experienced, highly trained welder, using a hand welding holder, and a helper. In each operation there are four welds: (1) welding a plug on the end of a steel tube to form one end of the mercury bulb; (2) welding a receptacle for the capillary on to the opposite end of the bulb; (3) welding the capillary tube to the receptacle end of the bulb and (4) welding the element head to the other end of the capillary.

John J. View is associated with Air Reduction Sales Co., Buffalo, N. Y.
Charles W. Pfleiger is associated with Partlow Corp., NewHartford, N.Y.

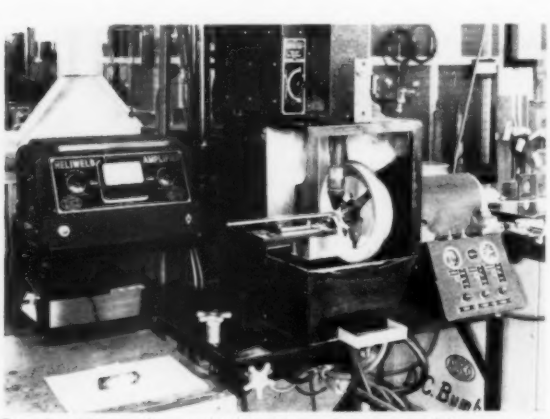


Fig. 1 View of gas-shielded tungsten-arc welding amplifier, holder, part to be welded and fixturing device

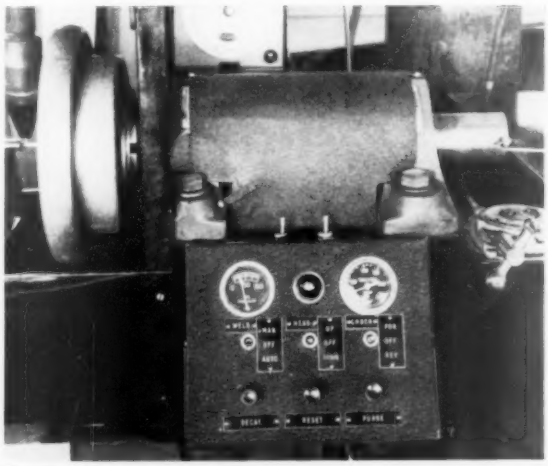


Fig. 2 Close-up of control panel

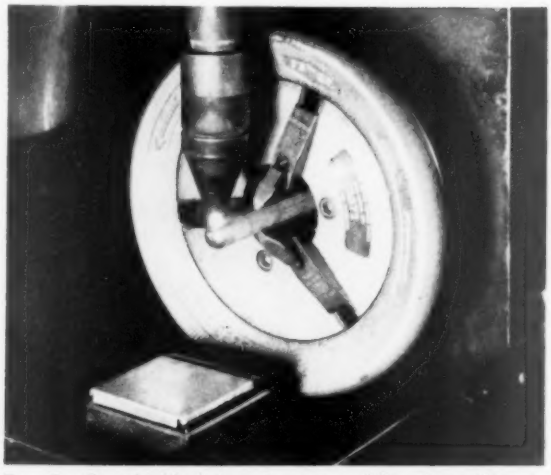


Fig. 3 Gas-shielded tungsten-arc welding in action on mercury bulb

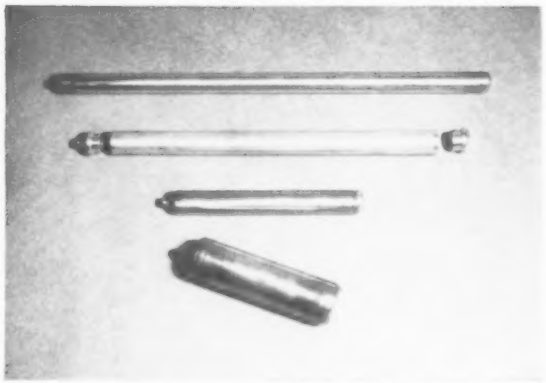


Fig. 4 Various mercury bulbs welded with the gas-shielded tungsten-arc process

The bulb is made of carbon steel, stainless steel or nickel, and its length and diameter is of a wide variety of sizes, as it is the volume of mercury in the bulb which determines the temperature range at which a particular instrument is to be operated.

Welds of the highest quality were a "must"—welds able to hold 5000 lb per square inch of pressure. Initial experimentation and adaption of gas-shielded tungsten-arc welding equipment was undertaken with the following objectives: increased production, tighter weld and improved appearance of the weld and uniformity.

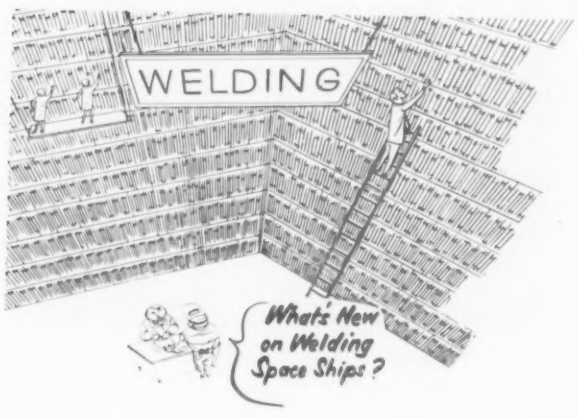
Under the old hand operation, the helper would turn the tube during welding. Often, after welding the bulb, welds required machining to achieve the proper smoothness. Often, the machine process would develop leaks.

Experiments indicated a need to design several of

Fig. 5 Over-all arrangement of equipment for the precision gas-shielded tungsten-arc welding of temperature-control instruments

the parts again, including the plugs and receptacles, in order to have the cross sections and thicknesses of these parts match the bulbs and capillary. A change was also made from aluminum-killed steel to silicon-killed steel for less porous joints. In addition, the manufacturer designed an automatic turning and timing device to work in conjunction with the gas-shielded tungsten-arc welding equipment. The operator now simply inserts the work in a special chuck and the work turns automatically under the welding electrode at the precisely controlled speed.

Figures 1 through 5 are typical illustrations of the welded mercury bulbs and of the equipment used to perform the welding operations.



The Welding Journal provides the most complete library of information on the art and science of welding available . . . anywhere. If you have a product for the welding or allied industries, the Journal's pages will reach your market.

HARD-SURFACING PASTE AIDS PRODUCTION OF ABRASION-RESISTANT SURFACES

BY L. V. LAROU

A relatively new hard-surfacing technique that is growing in favor is the use of hard-surfacing paste. Because it is a suspension of pure hard-surfacing crystals in a suitable vehicle, the resulting overlay is less diluted, producing the most abrasion-resistant surface obtainable with hard-surfacing techniques.

Description of Process

Unlike most hard-surfacing methods, paste application is not a build-up process. The part to which paste is applied becomes hard surfaced, rather, as a result of the alloying of its base metal with the paste. Penetration into the base metal is usually two to three times the applied paste thickness. Pound for pound, it will cover three times the area covered by rods or electrodes. This obviously contributes greatly to economy of application.

Hard-surfacing paste has found its greatest acceptance to date in the agriculture, foundry, construction and cement industries. This may be largely due to the fact that this material requires no finishing and is economical and easy to apply.

Hard-surfacing paste is usually applied to thin sections (under $^{3}/_{16}$ in.) with a brush or spatula and fused with an oxyacetylene flame. It is applied to thicker sections with a putty knife and fused by carbon arc. Nearly any contour may be overlaid with the paste material. For oxyacetylene-torch fusing, the maximum recommended overlay is 0.025 in. thick. For carbon-arc application to thick sections, 0.060 in. is the recommended maximum depth.

The area to be overlaid is first cleaned thoroughly by hand grinding. For brush application, the paste should be thinned to obtain the proper consistency. This is readily accomplished using water as the thinner. For thicker applications, a heavier consistency is preferred (about the consistency of mustard).

After application, the paste should be allowed to air dry. When thoroughly dry, it can be fused with an oxyacetylene flame or carbon arc as previously indicated.

L. V. LaRou is Vice-President, Engineering, Wall-Colmonoy Corp., Detroit, Mich.

Fig. 1 Spatula application of hard-surfacing paste to cultivator shovel blade. Maintenance and replacement costs were cut nearly 60% in this application

Fig. 2 Fusing the paste application

Fig. 3 Brushing on hard-surfacing paste to wearing edge of plow share

Fig. 4 Fusing paste to plow share using oxyacetylene torch

When using an oxyacetylene torch, heat is first applied to the base metal adjacent to the overlay. When the base metal becomes red, heat is advanced onto the paste until it sweats into the base metal. Sweating is distinguished by the darkening of the bright color of the paste. The torch should be moved along just fast enough to insure sweating. The surface should not be puddled.

When fusing with carbon arc, the carbon electrode should be ground to a long pencil taper. The carbon is positioned in the holder to provide about a 3-in. working length. Direct current, straight polarity should be used. Recommended amperage range is 90–120 with a $^1/_4$-in. diam electrode.

The arc is struck at the edge of the overlay and held just long enough to form a puddle. Weaving a crescent bead $^1/_2$ in. wide, puddling is continued until the entire overlay is fused. Care should be exercized to overlap adjacent beads by about $^1/_8$ in. to insure soundness of deposit. Excess puddling should be avoided as it can cause undue dilution of the overlay.

Applications in Industry

The thin overlays possible with hard-surfacing paste are very beneficial when used on agricultural equipment such as plow shares, disks and hand tools or on such wearing surfaces as flights of screw conveyors. The thin overlay does not create a dull edge; parts become self sharpening as the base metal wears first, leaving the alloyed hard-surfacing overlay to form a cutting edge.

The wear-resistant qualities of hard-surfacing paste are also used to advantage in the construction and cement industries where severely abrasive material handling applications are frequently encountered. Because of the heavier sections found in equipment used in these industries, heavier paste applications are more common.

Tops in the Industry!

The Welding Journal is the world's most authoritative welding and allied process magazine; it has fully 2½ times the editorial content of any competing magazine; it is unequalled in coverage of welding engineering, research and application. If you have a product for the welding or allied industries, the Journal's pages will reach your market!

HARD SURFACING IN FIELD AND SHOP KEEPS SLAG-RECOVERY OPERATION GOING

BY ROBERT HAAS

Probably one of the severest services to which hard surfacing is subjected is the equipment used to recover steel from slag dumps. Equipment costing millions of dollars receives arc-welded hard surfacing almost continually in both the field and shop, without which it would soon be on the scrap heap and economical operations would cease.

Slag is even more abrasive than lava rock, and, when it is interlaced with iron and steel as heavy as cement, even the toughest manganese-steel parts wear rapidly and must be hard surfaced frequently to continue in service. Wear strips are also welded on the most vulnerable surfaces and have to be renewed periodically.

For field welding, a truck of the type shown in Fig. 2 is used on the slag pile mentioned above. It includes a diesel-engine-driven d-c welder. This truck is driven close to the work and is equipped with a chain hoist that can be used to shift much of the work into favorable position, or, if preferred, work can be hoisted

Robert Haas is District Engineer at The Lincoln Electric Co., Cleveland, Ohio

Fig. 2 Truck equipped with a diesel-engine-driven 300-amp welding unit is used for hard surfacing wearing parts of equipment used on slag dump. It also carries other tools and a hoist

Fig. 1 Cast manganese-steel points are welded to worn dragline-bucket teeth with stainless-steel electrode for the first pass and manganese in the second

Fig. 3 Bulldozers of this type have a special heavy blade plus bolted manganese-plate cutting edges, much of which is protected from excessive wear by applying semiaustenitic electrode deposits. Beads are deposited in areas and directions indicated by experience. Electrodes of $^{5}/_{16}$ and $^{1}/_{4}$-in. diam are used. Track "shoes" are also hard surfaced on the inside (rail side)

aboard and taken to the weldery that is provided in an up-to-date machine shop on the dump, which may cover several miles.

Mobile earth-moving equipment, such as the bulldozer in Fig. 3 and the front-end loader in Fig. 4, is easily run into the weldery where the worn portions receive hard surfacing. Such work can be done at night or in off hours and still have the equipment ready for field use when needed.

Dragline buckets, such as shown in Figs. 5 and 6, are typical of large units that often are hard surfaced in the field, as it would require heavy and expensive equipment, as well as extra time to transfer the buckets to the weldery. As the photographs indicate, most external surfaces and many internal ones are protected first by extra-added plates and strips, and then by hard-surfacing beads. Most of such work is done with a semiaustenitic-type electrode because this type is relatively low in cost, yet provides excellent abrasion resistance and resistance to impact.

Fig. 4 Equipment such as this front-end loader is taken to shop located on the dump to receive hard surfacing. Note that extra added wear plates on side have been hard surfaced. A semiaustenitic-type electrode is used

On heel plates that are subjected to the hardest wear, a chromium-carbide-type electrode is employed because it has higher resistance to abrasion. This electrode provides miscroscopic crystals of very hard chromium carbide embedded in a tough, hard matrix that is excellent for the severe conditions that heel plates undergo.

This same electrode is also used on the face of lifting magnets (Figs. 7 and 8) used to pick up the chunks of fused iron or steel that are recovered from the slag pile. Cylindrical side surfaces of such magnets are covered with deposits of the semiaustenitic-type electrode. Without such hard coatings, these heavy 65-in. diam magnets would have short life. Chromium-carbide electrode is used for the outer ring and outer pole shoe.

Much of the work done in the shop involves repointing spare bucket teeth and the application of wear strips where these require renewal. Dragline-bucket teeth, which are manganese-steel castings, generally require repointing about once a month. This involves welding the new manganese-steel points to the old teeth.

In such work, the first welding pass is commonly done with a stainless-steel electrode and the second pass with a manganese electrode (Fig. 1). This

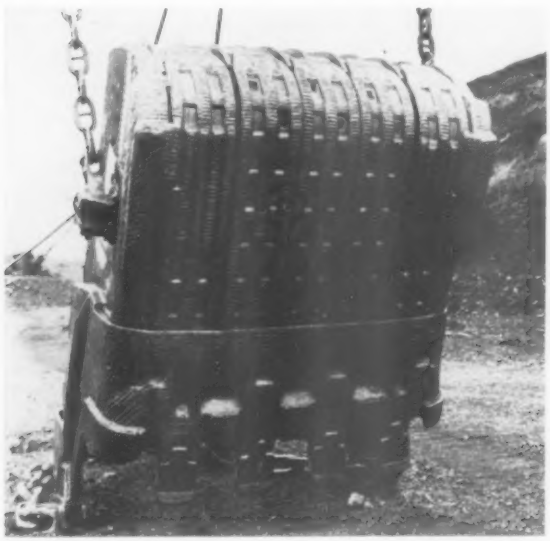


Fig. 5 Bottom surfaces of a dragline bucket showing many areas, including extra welded-on wear plates, on top of which hard surfacing has been applied by arc welding. The "teeth" are replaceable, but are also built up by welding as time permits. Note location and placement of beads

Fig. 6 Another dragline bucket, but showing some internal surfaces on which hard surfacing has been applied to reduce wear from highly abrassive slag. Note strips welded into inside of bucket, and also built-up hitchplates (hinges) and pins. Semiaustenitic-type electrode is used except for heel plates where chromium-carbide type is used

Fig. 7 This 65-in. circular lifting magnet handles large chunks of iron and has to be protected by applying hard surfacing on side faces each week to avoid destruction by the sharp edges and abrasive action of the slag

Fig. 8 Beads of chromium-carbide electrode are applied to the edge of the outer ring and to the center pole shoe of this 65-in. lifting magnet to protect these parts from the rapid and destructive wear encountered

insures strong joints, but with minimum consumption of the more expensive stainless steel. Beads of semi-austenitic electrode are added to areas where wear is greatest.

TUNGSTEN-ARC WELDING SOLVES FABRICATION PROBLEM

Six fabrication methods were tested to find the best method for eliminating costly slowdowns and shutdowns caused by tube leaks in a carbon-steel heat exchanger. The winner: the inert-gas-shielded tungsten-arc welding process.

The heat exchanger, which operates under a steam pressure of 400 psi, is installed at the Wood River, Ill. refinery of Shell Oil Co. It is part of the solvent-recovery system of the extraction plant which processes lubricating oil.

Tubes for the exchanger were originally rolled from steel sheets, but continually developed leaks despite repeated re-rolling. The tubes were then seal-welded, but these welds developed cracks and proved unsatisfactory.

To solve the problem, an extensive experimental program was recently undertaken by Shell Oil engineers. Included in the program were two welding processes, tungsten-arc welding, covered-electrode welding and four mechanical methods. The six methods were used to make tube installations for an experimental heat exchanger which was then tested under conditions more severe than normal operation.

During hydrostatic and tensile tests, the experimental tubes were exposed to heating and cooling cycles to simulate: (1) thermal conditions similar to operation; and (2) thermal shock which occurs at shutdown. The results: mechanically made joints failed under these conditions; welded joints did not.

Competition was now narrowed down to the two welding processes and macroexaminations were made to compare the test welds. The results: tungsten-arc welds, made with a special low-carbon steel filler rod, were superior to covered-electrode welds in both weld penetration and density.

Now, there are no more leaks in the heat exchanger. The problem has been solved and costly shutdowns eliminated. . .another of the many fabrication problems solved with tungsten-arc welding.

Fig. 1 With the leak problem solved, tubes are tungsten-arc welded to a tube sheet of a heat exchanger

Based on a story by the Linde Co., New York, N. Y.

Society News

AWS Bylaw Revisions to Be Presented to Membership for Approval

Board of Directors Submits New Plans to Streamline Activities and to Encourage Experienced National Representation

The entire membership of the AMERICAN WELDING SOCIETY will soon have an opportunity to vote on an issue of major importance which is designed to promote greater efficiency within the organizational structure of the SOCIETY. Provisions are also made to assure that those who have served the SOCIETY will be chosen to establish its policies and plan its activities.

New Structure of National Officers

At the April 17th and June 5th meetings of the Board of Directors official approval was given to the establishment of these revisions as "temporary bylaws," subject to the final approval of the AWS membership.

Under the proposed plan, there will be a president, *three* (now two) vice-presidents *without seniority*, an *appointed* treasurer, *thirteen* (now twelve) directors-at-large, eleven district directors serving *three* (now 2-year) terms, an executive secretary and *two* (now three) past-presidents. (Italicized words indicate changes from current bylaws.) Minimum qualifications covering experience in SOCIETY activities are given for members of District and National Nominating Committees and for all national officers.

The over-all leadership of the SOCIETY will emanate from three main sources, consisting of (a) the elected Board of Directors, (b) the Executive and Finance Committee, and (c) four Functional Councils, namely: Administrative, Technical, Districts, and Publication and Publicity. If the new plan is approved by the membership, all special and standing committees will report to one of the Functional Councils, with the exception of a very small group that will report directly to the Executive and Finance Committee. Final authority will remain within the Board of Directors; however, normal activities will be supervised by the Executive and Finance Committee acting through the four Functional Councils. Under the new structure, the president will be chairman of the Board of Directors and of the Executive and Finance Committee. The four Functional Councils will be headed by the three vice-presidents and a past-president. Each member of the Board of Directors will serve on at least one of the Functional Councils and, possibly, on the Executive and Finance Committee.

Revised Organization Under Study for Over Three Years

The initial steps in the reorganization of the SOCIETY's structure were taken at a meeting of the AWS Executive Committee held on Apr. 29, 1955, when President J. H. Humberstone was empowered to appoint a special committee to study the organization structure of the SOCIETY. The present National Secretary was appointed chairman of this early group which also included J. H. Blankenbuehler, A. F. Chouinard, G. O. Hoglund, T. E. Jones, A. N. Kugler, C. I. MacGuffie, H. E. Rockefeller, C. M. Styer and Mr. Humberstone. These original members were

AWS DIRECTORS-AT-LARGE

Term Expires 1959	1960	1961
J. H. Blankenbuehler	J. F. Deffenbaugh	A. A. Holzbaur
G. E. Linnert	A. E. Pearson	D. B. Howard
P. G. Parks	C. M. Styer	C. E. Jackson
F. H. Stevenson	R. M. Wilson, Jr.	J. L. York

AWS DISTRICT DIRECTORS

District No. 1•New England Sidney Low	*District No. 6•Central* J. N. Alcock
District No. 2•Middle Eastern E. E. Goehringer	*District No. 7•West Central* A. F. Chouinard
District No. 3•North Central H. E. Miller	*District No. 8•Midwest* F. G. Singleton
District No. 4•Southeast E. C. Miller	*District No. 9•Southwest* P. V. Pennybacker
District No. 5•East Central H. E. Schultz	*District No. 10•Western* F. V. McGinley
	District No. 11•Northwest C. B. Robinson

OTHER DIRECTORS

Junior Past-President J. H. Humberstone	*Junior Past-President* C. P. Sander
Junior Past-President J. J. Chyle	

later joined by I. A. Oehler, J. J. Chyle and C. P. Sander.

For some time, the need of a comprehensive study of the entire organizational structure of AWS had become increasingly obvious. Established in 1919, the existing organizational structure had adequately served a society of 5000 or fewer members which had limited and relatively simple activities. However, with greatly increased membership and rapidly expanding activities covering broader fields of interest, an ever increasing burden was being imposed upon the Board of Directors and the staff. Continuing requests to perform new tasks and to explore new fields of interest for the welfare of its membership and the welding industry, indicated that it was imperative that the SOCIETY organization structure be revised if the SOCIETY were to perform the function for which it was created and attain the objectives it had established as its goal.

Special Committee Holds Many Meetings

As a result of many meetings of this special committee, the existing organization structure of the SOCIETY was summarized on a chart labeled Plan No. 1. Subsequent meetings culminated in the alternative Plans No. 2, 3, 4, 5 and 6. It became obvious that it was advisable to reorganize and to solidify the over-all top-management structure and also to restudy the activities and scopes of all committees. Plan No. 7, representing the thinking of the special committee after one and one-half years of deliberation, was distributed on Sept. 26, 1956, and approved with a few minor modifications by the Board of Directors at a meeting held in Cleveland on Oct. 11, 1956.

Further Studies Result in Final Approval

A survey of the scope and activity of all special and standing committees was then conducted. The results from this survey were studied at a meeting held on May 10, 1957, and then delivered with recommendations to A. F. Chouinard, who had been appointed chairman of the Special Committee in June 1957. In November 1957, Mr. Chouinard reported that recommendations of his committee had been submitted to the Constitution and Bylaws Committee for the preparation of suitable bylaws. The chairman of the latter Committee, I. A. Oehler, reported to the Board of Directors on the bylaw changes approved by his group and by the Organization Structure Committee at a joint meeting on Feb. 24, 1958. The changes were finally approved by the Board of Directors at its meetings on April 17th and June 5th.

Bylaw Proposals to Appear in November Journal

The complete text of these revised bylaws will be published with additional comments in the November issue of the WELDING JOURNAL. Any member desiring a copy of the current yearbook section, including the latest edition of the bylaws, may secure the same by sending his request to: Secretary, AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

Fred L. Plummer

THINGS YOU SHOULD KNOW

(That Happened in August)

● Most of your staff members enjoy at least short vacations during the summer months. However, these are busy days at Headquarters filled with the preparation of various publications and plans for another year of expanding activities.

● Yearbook sections covering (a) awards, (b) 1957–58 Finances, and (c) National Officers and Members of all standing and Special Committees, have been compiled, reproduced and distributed. Additional sections listing (d) members of Technical Committees and (e) Sustaining Members and Supporting Companies with a complete membership report, are being prepared along with the new Section Officers' Directory. New manuals covering Section operation and Convention Committee activities have been completed.

● National Membership Chairman Tom Dempsey has prepared effective "memos" for distribution each month to some four hundred officers and members responsible for membership activities. A new and convenient application form has been prepared to aid those helping to expand the services of the SOCIETY. During August, bills must be prepared and mailed to more than six thousand members who have a September 1st anniversary.

● Headquarters' office has been revised to provide facilities for the new Information Center which is now beginning to function under Secretary for Information and Education Art Phillips. A partition was removed from the Secretary's office and installed in the former board and committee room which will now house the new department. Pictures of Founder Comfort A. Adams and long-time Secretary Marguerite M. Kelly, as well as those of our 32 Past Presidents and President Hoglund, have been installed in the Secretary's office which will now also serve as a meeting room for regularly held staff conferences and for the meetings of such important committees as Executive, Finance and Exposition. All members are cordially invited to visit this enlarged and redecorated office which more fittingly represents the importance and breadth of activities of our SOCIETY.

● Handbook Editor Art Phillips cut short his vacation in order to push the production of Section II of the Fourth Edition of the Welding Handbook. The thirteen chapters of this section will cover Gas, Arc and Resistance Welding Processes and supplement Section I on Fundamentals which was distributed late last year. The new section should be ready for distribution soon after you read this statement.

● Several years ago, members of our Detroit Section organized a working group and sponsored the preparation of recommended standards covering space and equipment requirements, and subject outlines for vocational training in welding and allied processes. These standards were reviewed by national committees, although they were never developed in final form. Last May, President Hoglund and your Secretary met with representatives of the Detroit Section and the American Vocational Association to discuss the preparation of such standards in a form similar to that of the very successful standard for Automotive Service Instruction in Schools. On August 10th your Secretary, accompanied by A. D. Althouse, assistant director of Vocational Education for the Detroit Public Schools, met in Buffalo with the AVA Trade and Industry Policy and Planning Committee to discuss this important project further. Our Educational Activities Committee, with Clarence Jackson as chairman, is organizing special committees to complete the preparation of these standards, and active cooperation with the American Vocational Association is anticipated.

● In addition to Ohio State University, Utah State University and LeTourneau

Technical Institute now give degrees of Bachelor of Science in Welding Engineering following successful completion of four years' study.

● Technical Secretary Ed Fenton reports complete revision and early production of our widely used Welding Symbols. The new Soldering Manual is essentially completed and will soon be published as a suitable companion volume to the authoritative Brazing Manual. The July issue of *ASTM Bulletin* includes an article on the activities of the AWS Subcommittee on Nuclear Power Piping. Recent issues of *Metco News* call attention to AWS Standard Metallizing Symbols and other important AWS technical activities.

● JOURNAL Editor Bonney Rossi has released several interesting statistics which were developed in a survey conducted at the request of a leading advertising agency. These clearly demonstrate the outstanding coverage and effectiveness of advertisements placed in the WELDING JOURNAL.

● Elsewhere in this issue you will find a statement about proposed changes in bylaws to make possible the more effective functioning of your SOCIETY organization. Please read these carefully and look for further comments in the November JOURNAL.

● Visitors at Headquarters during the first three weeks of August included a representative of a firm interested in the manufacture of welded furniture in Australia; Hans Reichert, who is head of a firm in Austria concerned with nonferrous metals; Clarence Jackson for a discussion of a paper on the welded Atomium at the Brussels Fair and a conference on educational activities; Bob Kenworthy for conferences on the 1959 Chicago and 1960 Los Angeles Expositions and the preparation of data for use of the Exposition Committee in selecting sites for the 1963 and 1964 Expositions; and O. T. Barnett, whose new book, *Filler Metals for Joining*, will soon be published by the Reinhold Publishing Corp.

● An important meeting concerning investment of our Reserve Funds was held in your Secretary's office on August 11th with Past-President J. H. Humberstone, Marine Midland Trust Co. Ass't. Vice-President F. D. Cekich, SOCIETY Auditor Jerry Landau and Ass't. Treasurer Frank Mooney in attendance.

● Several staff meetings have been devoted to the development of suggestions to be submitted to the Convention Committee concerning the 1959 fall meeting which will be held in Detroit during the week beginning September 28th.

● The annual meeting of the PVRC, scheduled for Friday, September 26th, will be different this year. Professional assistance is being used in developing a dramatic presentation of the important activities of this group during the past decade. Your Secretary, who has served as leader of this group for several years, will turn over the chairmanship to T. N. Armstrong following this meeting.

● August 19th was marked by the completion of a major phase in another outstanding welding accomplishment—symbolized by the launching at Groton, Conn., of the newest and the largest atomic-powered submarine, the Triton. This 5900-ton, double-walled pressure vessel, constructed of high-tensile steel and housing 88,000 ft of stainless steel and other metal piping, would not have been possible without welded fabrication for which 450,000 lb of electrodes were used. Following the launching, which was witnessed by some 35,000 interested spectators, your Secretary together with Mrs. Plummer, Mr. and Mrs. R. K. Lee, and Dr. Robert Stout attended a special research and development group luncheon at the Submarine Base Officers Club and discussed welding problems with Dr. J. Ballass of the Electric Boat Division of General Dynamics Corp.

● Important meetings which will be held before you read these notes include one of the Publicity Committee scheduled by Chairman Al Scherer for September 9th in Cleveland, one for organizing the new AEC Advisory Committee, called by Chairman and Past-President J. J. Chyle to meet in the Secretary's office on September 11th and one for the Technical Papers Committee, with Tom Armstrong presiding on September 18th, to select papers for the 1959 Annual Meeting in Chicago. On this same day your Secretary will speak before a meeting of the American Gas Association in Tulsa and then join Exposition Manager Kenworthy and staff members Mooney and Phillips in Chicago to meet with Chairman L. S. McPhee and members of his arrangements committee for the 1959 Convention and Exposition, and attend the September 19th meeting of the Chicago AWS Section. A late September meeting is planned by Chairman Ted Long of the Exposition Committee, prior to the next meeting of the Board of Directors, which will probably be held in Detroit on October 10th, following a meeting of our Educational Activities Committee there the preceding day and followed by the October 10th meeting of the Detroit AWS Section. The New England Sections are planning another outstanding welding conference for October 23rd in Providence. President Hoglund will speak before the San Francisco Section on October 20th and will attend meetings of the AEC Welding Committee in Richland, Wash., the preceding week.

Fred L. Plummer

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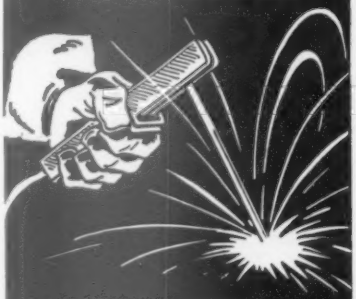

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EDUCATIONAL ACTIVITIES

Teaching the Art of Welding

By H. A. Sosnin

H. A. Sosnin

One of the many ways in which the AWS can help others to utilize the advantages of welding is through its training programs. Wherever metals are used, a knowledge of welding is almost indispensable. Welding, therefore, should be incorporated into the training of all who intend to enter these fields.

The AWS Apprentice Training Committee has recognized this need and is actively engaged in trying to have welding introduced into all applicable apprentice training programs. This objective will not be achieved overnight. It is a long-term policy which will gain impetus as more and more organizations adopt the new concept. Welding has become an almost universal tool. It is comparable to the hammer and the saw. Welding is common to all industries and a man without a knowledge of welding is likely to find himself severely handicapped.

In some fields a welding program is well under way. In others, observers have been assigned to evaluate apprentice programs and report back to the parent organization. The United Association of Plumbers and Pipefitters is far ahead of most such groups in ungrading and educating members of their organization. A very competent training department is in operation and results are more than satisfactory. The AWS Apprentice Training Committee has lost no opportunity to help this program along and render all possible assistance.

In March 1958, Ralph Minga, an active member of the Apprentice Training Committee, and Bill Oldershaw spent three weeks in Washington, D. C., conducting a course in inert-gas-shielded arc welding for pipefitter journeymen. This course was held five evenings a week for three weeks. The enthusiasm with which this course was received, by both men and management, was encouraging.

During July 1958, I personally conducted a course on oxyacetylene welding and coated-electrode arc welding. The students for this course also were journeymen.

It is very obvious, during these courses, that the men themselves are most anxious to further their education. They realize that their future usefulness may well depend upon their ability to use the torch or the arc. During sessions, it is rare to see attention lagging, and the questions asked are good indications of their interest in the subject. There is a great need for more such classes. It is gratifying to report that the plumbers and pipefitters are planning many more courses on welding throughout the country.

This is one more way in which the AMERICAN WELDING SOCIETY through its educational committees is helping industry to use the best and most up-to-date joining methods.

H. A. Sosnin is chairman of Committee on Apprentice Training and associated with Tube Turns.

An apprentice begins welding overhead after only 35 hr of instruction and practice

A group of students at the Washington Plumbers and Pipefitters school are eager for instructional materials

Section News and Events

as reported to Catherine O'Leary

New AWS Section Formed at Nashville, Tennessee

The Board of Directors of the AMERICAN WELDING SOCIETY recently announced the formation of a new section at Nashville, Tenn. The charter was granted on July 1, 1958.

The first elected officers of the *Nashville* Section include the following individuals: Burton C. Hawarth, chairman, E. I. du Pont de Nemours & Co.; John L. Bevill, vice-chairman, Kerrigan Iron Works; Robert W. Liddle, secretary, Ford Glass Plant; and W. E. Moran, treasurer, Nashville Bridge Co. W. Michael Belew, Eutectic Welding Alloys Corp., and Russell Staub, Industrial Electric Co., were respectively elected membership and program chairmen. Elections to the new executive committee for the Section include Jules U. Durham, American Bureau of Shipping; Miller C. Minton, Nashville Bridge Co.; and John H. McCann, McCann Steel Co.

The addition of the *Nashville* Section raises the national total of AWS sections to 81. It also becomes the fourth section to be formed in the state of Tennessee. The first one was started in Chattanooga in 1937, the second in 1952 and the third in 1954.

It is reported that over 50 members are enrolled at this stage of the new section's development.

SECTION MEETING CALENDAR

OCTOBER 10

COLUMBUS Section. "Certification of Welders," R. S. Green, Engineering Experiment Station, Ohio State University.

OCTOBER 13

NORTHWEST Section. Minneapolis, Minn. "CO_2 Shielded Welding Automatic and Semi-Automatic," J. A. Howrie.

OCTOBER 15

PITTSBURGH Section. Mellon Institute, Pittsburgh, Pa. 6:30 P.M. dinner, 8:00 P.M. technical session. "Modern Techniques in Brazing," Donald C. Herrschaft, Handy & Harman.

OCTOBER 20

PHILADELPHIA Section. Engineers' Club, Philadelphia, Pa. 8:00 P.M. "Metallurgy of Ferrous Welding," Dr. W. D. Doty, U. S. Steel Corp.

OCTOBER 21

OLEAN-BRADFORD Section. Emery Hotel. Bradford, Pa. Dinner, Jade Room 7:00 P.M. Meeting, Burgundy Room, 8:30 P.M. "Welding of Aluminum and the Performance of Welded Aluminum Assemblies," W. M. Rogerson, Aluminum Company of America. Guest: G. O. Hoglund, AWS President.

NOVEMBER 3

WORCESTER Section. Nick's Colonial Grill, Worcester, Mass. Social 6:00 P.M. Dinner 7:00 P.M. Meeting 8:00 P.M. "Future Methods of Operations for Resistance Welding," Stuart Rockafellow. Robotron Corporation.

NOVEMBER 4

PITTSBURGH Section. (Johnstown). V.F.W. Post No. 155, Johnstown, Pa. "Manual Metal-Arc Welding," D. H. Marlin, Dravo Corporation; William H. Kauffman, Williams & Company.

NOVEMBER 7

DETROIT Section. Engineering Society of Detroit. Dinner 6:15 P.M. Meeting 8:00 P.M. "Welding of Structural Steel."

PHILADELPHIA Section. Junior Conference Room, Engineers Club, Philadelphia, Pa. 8:00 P.M. "Metal Spraying," A. Ford, Moderator.

NOVEMBER 11-12

NORTHWEST Section. Minneapolis, Minn. "Metals and How to Weld Them." Northwest Welding Conference at U. of M.

NOVEMBER 13

PUGET SOUND Section. Engineers' Club, Seattle, Wash. "Newest Developments in All-Position, Semiautomatic Welding of Mild Steel," Harry J. Bichsel, Westinghouse Electric Corp.

NOVEMBER 14

COLUMBUS Section. Columbus, Ohio. "Selection of Ferrous Electrodes," Columbus Section Panel.

NOVEMBER 17

PHILADELPHIA Section. Engineers Club, Philadelphia, Pa. "Resistance Welding at the Budd Company," Byron Gates and others, the Budd Company.

NOVEMBER 19

PITTSBURGH Section. Auditorium, Mellon Institute. "How to Meet Government Code Requirements."

Editor's Note: Notices for January 1959 meetings must reach Journal office prior to October 20, so that they may be published in December Calendar. Give full information concerning time, place, topic and speaker for each meeting.

NEW ENGLAND SCHEDULES WELDING CONFERENCE

The Third New England Regional Welding Conference, entitled, "Better Quality and Greater Profits thru Welding in New England," will be held Thursday, Oct. 23, 1958, at the Elks' Auditorium in Providence, R. I. The one-day program will include educational sessions, welding demonstrations and technical sessions. Registration will commence at 9:00 A. M. A $3.50 fee will be charged.

During the morning, three educational sessions will take place, the first on structural welding at 9:45, and the second on welding of tanks, pressure vessels and piping at 10:45, and the last on "cost cutting thru welding" at 11:45. After the 12:45 luncheon, welding demonstrations and technical sessions will be held simultaneously throughout the afternoon. The demonstrations will last from 2:00 until 5:00 P.M. and will include present-day welding techniques with explanations on the welding of stainless steels, aluminum, piping and cast iron. Three separate technical sessions will be held at 2:00, 3:00 and 4:00 P.M. The subjects covered will be "Inspection of Weldments," "Welding for Nuclear Service" and "Brazing for High-Temperature Service."

A 6:30 P.M. banquet will be preceded by a social hour. Closing out the day's activities will be a discussion of the qualification and training of welders at 8:00 P.M.

NEW OFFICERS FOR COMING SEASON

The *Columbus* Section has announced its elected officers, directors and committee chairmen for the coming 1958—59 season. The new officers are Robert A. Bowers, Williams and Co., Inc., chairman; Raemon P. Sopher, Battelle Memorial Institute, vice-chairman; Herbert W. Mischler, also from Battelle, treasurer; and Robert S. Ryan, Columbia Gas System Service Corp., secretary. Newly elected directors include Charles Meinhart, North American Aviation, Inc.; William Green, Ohio State University; Milt J. Randall, Battelle; C. G. Fosnaught, Williams and Co., Inc; Howard Balthasas, Welding and Mechanical Supplies, Inc.; and Robert McMaster, Ohio State. Nine new committee chairmen were appointed. They are James Giorgione, membership; W. G. Leaman, education; Frank Smith, attendance; Jack E. Lott, publicity; Richard Grant and Loren Alspach, social co-chairmen; Mel Clapp, auditing; Charles Meinhart, CTC representative; and William Green, technical representative.

AWS MEMBERS MEET WITH OTHER GROUPS IN CALIFORNIA

Studying a brochure at a joint meeting of AWS, ASTE and ASM in Sacramento on June 16th are *(left to right)*: Arthur S. Dzigorski, ASTE chairman of the Sacramento Chapter; Francis H. Stevenson, AWS Director-at-Large; Chairman Jack P. Porter of the AWS Sacramento Section; and Dr. E. R. Mertz, ASM chairman of the Sacramento Chapter

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For copies of articles, write directly to publications in which they appear. A list of addresses is available on request.

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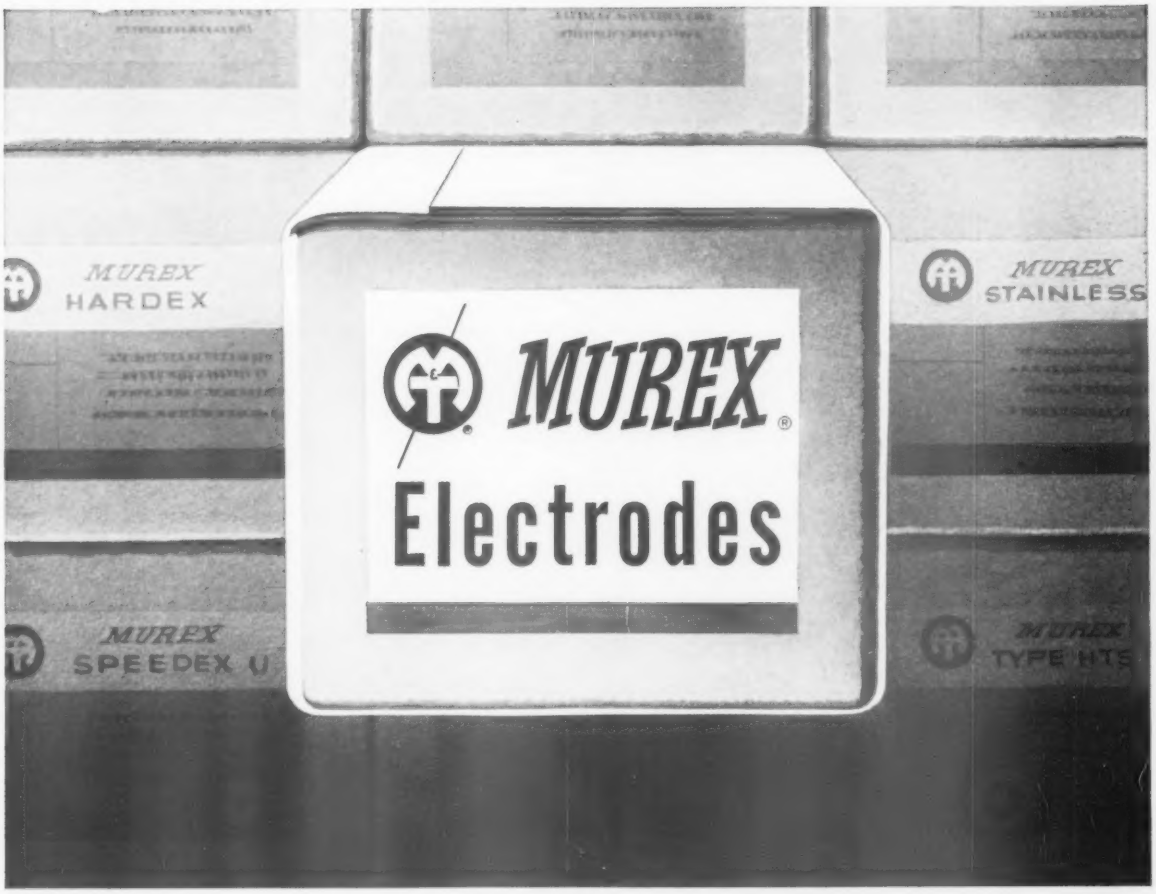

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ABSTRACTS OF CURRENT PATENTS

prepared by Vern L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington, D. C.

2,814,715—Percussive Welding Arc Starting Devices—David E. Blackmer, Reading, Mass., assignor to Raytheon Manufacturing Co., Waltham, Mass., a corporation of Delaware.

This patent relates to welding apparatus of the type having a fixed and movable workpiece holder with means for applying a welding current to the workpieces when in contact. A high-frequency oscillator is connected across the workpieces. A source of direct current is shunted by a resistor, a capacitor and the primary of a transformer, while the secondary of the transformer is shunted by a second capacitor of less capacity than the first and coupled to the movable workpiece by an arc discharge path. A switching device is provided to initiate an arc across the path and activate the oscillator under control of the movable workpiece holder.

2,814,716—Stud-Welding Method and Device—Thomas E. Shoup, Amherst, Roger W. Sholle, Lorain, and Lorenz John Mowry, Elyria, Ohio, assignors to Gregory Industries, Inc., Detroit, Mich., a corporation of Michigan.

This patent is on a stud-welding device including a housing, a stud carrying member, and resilient means urging the stud carrying member away from the housing. A solenoid is provided and includes an armature operatively connected to the stud carrying member and a coil capable of overcoming the resilient means and drawing the armature and the stud carrying member towards the housing. Other means are provided for supplying welding current to a contactor on the stud carrying member and for timing the welding circuit duration.

2,814,717—Resistance Welding—Ethridge E. Hardesty, Balboa Island, Calif., assignor to Fairchild Engine and Airplane Corp., Hagerstown, Md., a corporation of Maryland.

A method of resistance welding is disclosed by the present patent. The method includes providing an irregular surface on one face of a metal sheet and abutting an edge of a thin metal supporting strip against the irregular surface. A welding current is then passed through the sheet and the strip to weld them together.

2,814,718—Resistance-Welding Methods and Apparatus—Ethridge E. Hardesty, Balboa Island, and Ansell K. Hill, Costa Mesa, Calif., assignors to Fairchild Engine and Airplane Corp., Hagerstown, Md., a corporation of Maryland.

This patent on resistance-welding processes is for welding a metal sheet to the edges of a thin walled metal supporting element. First a metal mesh is welded into the edges of the supporting element and the sheet is urged against the mesh and the edges. A welding current is passed between the sheet and the supporting element for welding action.

2,814,719—Automatic Electric Arc-Stitch Welding—Jack L. Wilson, Niagara Falls, N. Y., assignor to Union Carbide Corp., a corporation of New York.

This welding action utilizes a continuously fed fusible metal electrode and the workpiece is moved with relation to the electrode along the path to be welded. A series of self-regulating arcs are struck between the workpiece and the end of the moving electrode and arc welding current is supplied to each of such arcs to melt the electrode at a rate greater than the feeding rate to fuse the end portions of the electrode and spaced portions of the workpiece along the path of relative movement therebetween. Hence, a series of uniformly spaced separate welds is provided in the workpiece without interruption in movement of the electrode.

2,815,282—Nickel - Manganese - Palladium Brazing Alloy—Edwin Clements Rhodes, Ealing, London, and David Wade Rhys, Hounslow, England, assignors to the International Nickel Co., Inc., New York, N. Y., a corporation of Delaware.

The patented new brazing alloy is for brazing heat-resistant chromium-containing alloys intended for high-temperature service on the order of about 550 to 850° C. The new alloy comprises about 28 to 67% nickel, between 16 and 40% manganese and the balance essentially all palladium. The alloy has a melting temperature of between 1050 and 1250° C.

2,815,436—Welding Aluminum-Clad Steel—Julius Bland, Munster, Ind., assignor to Standard Oil Co., Chicago, Ill., a corporation of Indiana.

Bland's patent is for welding aluminum clad steel members having edges which are juxtaposed and in welding relationship to one another. The method includes the welding of aluminum edges of the aluminum clad steel members with a nonconsumable electrode while the molten portions of the weld are blanketed with an inert gaseous medium. Next a root pass is welded between the steel edges of the aluminum clad steel members while avoiding impingement of the arc from the electrode upon the aluminum cladding and while blanketing the molten portions of the weld with an inert gaseous medium. Then the weld is completed between the steel edges.

2,815,437—Resistance-Welding Machine—Eo Reed and James C. Young, Middletown, Ohio, assignors to Armco Steel Corp., Middletown, Ohio, a corporation of Ohio.

The present patent is on a machine for welding metal sheets end to end to form a strip. The machine includes a pair of rails disposed transversely to the direction of travel of the strip and approximately in the plane of the strip travel. A carriage carrying a resistance-welding wheel in a position to ride over the seam to be welded is positioned on the rails for reciprocation thereon. The carriage also positions a backing wheel vertically directly beneath the welding wheel below the plane of strip travel. Means clamp the butted edges of the sheets for welding action and other means supply welding current to the welding wheel as the carriage is moved transversely of the strip for a welding pass.

2,815,729—Composite Brazing Pellet—Isaac S. Goodman, Belleville, N. J., assignor to Westinghouse Electric Corp., East Pittsburgh, Pa., a corporation of Pennsylvania.

This novel composite brazing pellet is for use in brazing lead conductors to sealed beam lamp ferrules. The pellet is made from an unsintered homogeneous mixture of finely divided brass and flux. The brass has a copper content of between 50 and 70%, and the flux consists essentially of borax in amount of from about 1 to 5% by weight of the brass.

2,816,208—Electric Weld Tube Mills Inside Spreading Rolls at Electrode—William Stewart McDowall, Youngstown, Ohio, assignor to Republic Steel Corp., Cleveland, Ohio, a corporation of New Jersey.

This patent relates to apparatus for resistance welding the longitudinally extending, opposed edges of an endwise moving tubular blank. The apparatus includes an elongate member disposed in the blank and fixed against longitudinal movement. A roll carrier is attached to the member adjacent to the place of welding, and a roll is supported on one side of the carrier and disposed to engage the blank adjacent its opposed edges just ahead of the welding zone. Such roll is adjustable both longitudinally and radially in the apparatus. Other rolls are spaced longitudinally from the first roll and are positioned to engage the inner surface of the blank.

NEWS of The Industry

800 Engineers Flock to Vienna for Annual Meeting of the IIW

More than 800 engineers from 24 countries attended the meeting of the Annual Assembly of the International Institute of Welding in Vienna, Austria, from June 29th to July 5th. Representation from the United States included the following individuals: W. Spraragen, F. L. Plummer, D. K. Felbeck, J. H. Zimmerman, F. W. Hussey, E. J. Brady, M. G. Sedam, T. E. Jones, M. L. Begeman, F. R. Woodward, R. A. Pulk, R. D. Stout, M. Cohen, T. J. Griffin, C. E. Hartbower, G. Place, P. P. Puzak, L. J. Larson, A. R. Gatewood, C. W. Wheatley, Z. Gezari, P. R. R. Scarr, J. E. Stallmeyer, B. Thurlimann and A. Amirikian. Sponsor representatives on the American Council of the IIW were Mr. Plummer, AMERICAN WELDING SOCIETY; Mr. Felbeck, Ship Structure Committee; and Mr. Spraragen, Welding Research Council.

Delegates Hear 31 Papers at Public Session

The Public Session was held on June 30th at the Town Hall in Vienna. Thirty-one papers from 15 countries were presented at this session, all dealing with various aspects of the principal theme, "Welding in the Chemical Industry." Two American papers were included in this program. They were "Welding of High-Nickel Alloys for Chemical Plant and Equipment" by R. P. Colbertson and R. C. Perriton and "Evolution of the Hanford Technique for Inert-Gas Welding of Austenitic Stainless-Steel Piping Systems" by E. B. La Velle. Each paper presented at the Public Session was based on one of the following five subthemes: influence of the method of welding, of preheating and of finishing operations on the properties of welded assemblies in comparison with those of the base metal; welding of clad metals, lining; special problems in the welding of equipment for the chemical industry and for nuclear plants; design and calculation of welded products working under high pressure and at high temperatures; and typical examples of welded constructions.

Commissioners Discuss Problems

One of the most important functions of the IIW concerns the work of its committees or Commissions, as they are called. Commission discussions were held on many phases of welding and cutting in addition to studies of such areas as design, safety and training procedures. Several works were approved for publication under the auspices of the IIW by the Governing Council. Included in this group will be a list of terms used in ultrasonic welding, supplements to the "Arc Welding" section of the Multilingual Collection of Terms, a handbook on "Health and Safety in Welding and Allied Processes" and another handbook on radiographic apparatus and techniques.

New Member Societies Admitted

The following societies were elected to membership of the Institute: Argentine Institute of Welding; Paton In-

This partial view of the interior of Vienna's Town Hall shows some of the delegates and guests in attendance at the Opening Session of the 1958 Annual Assembly of the International Institute of Welding on June 30th. Translations of speeches were available in four languages through the use of radio headphones

Delegates and experts of Commission X—"Residual Stresses and Stress Relieving"—pool their knowledge during one of their sessions. Seated on the extreme left of the front row are Expert W. Spraragen and Delegate L. J. Larson. Jim Stallmeyer is at extreme left, rear row. This meeting was one of 15 Commission conferences held during the week-long convention

stitute of Electric Welding of the Academy of Science of the Ukranian Republic; Institute of Metallurgy of the Academy of Sciences of the Soviet Union; Serbian Society for Advancement of Welding (Jugoslavia); and four other Soviet groups. As a result of these new members, the IIW now consists of 58 member societies representing 27 nations.

1959 Assembly to Be Held in Jugoslavia

The 1959 Assembly will be held at Opatija, Jugoslavia, from June 28th to July 4th. The principal theme of the next Public Session will be "Welding and Allied Processes—Gas Cutting, Building-Up, Bronze Welding, Surface Hardening, Metal-Spraying—in Maintenance and Repair Work."

The Austrian meeting would have been incomplete without the usual American "bull session." Participating in this cherished Yankee custom are *(left to right)* L. J. Larson, T. Embury Jones, P. P. Puzak, Frank W. Hussey and C. E. Hartbower. These men served as delegates to the European convention

Airco to Build in Kansas City

Announcement has been made by Air Reduction Sales Co., a division of Air Reduction Co., Inc., of the breaking of ground for construction of a new oxygen and nitrogen producing plant in the Armourdale district of Kansas City, Kan.

The new plant, which is designed to serve users of industrial gases located within a 300-mile radius of Kansas City, will have a monthly capacity of 5 million cu ft of oxygen. In addition, high-purity nitrogen will also be produced at the plant.

It is anticipated that construction will be completed and the plant in operation during December 1958.

American Bureau of Shipping Elects 5 New Members

As announced by Walter L. Green AWS, chairman of the board, five individuals were recently elected to the membership of the American Bureau of Shipping. The new members are Edward J. Flynn, John G. Gilbridge, Gene C. Hutchinson, J. Arthur Marquette and Dale E. Taylor.

Robotron Enters International Markets

Extension of licensed manufacturing and sales facilities to serve international markets is announced by Robotron Corp., 21300 W. Eight Mile Rd., Detroit, Mich.

Initial programs for overseas operations will be handled by Radiovisor Parent Ltd., High Path, London, England, and Electrical Control & Engineering Ltd., Camperdown, Sydney, Australia. The English concern will cover all industrial markets in the British Isles and continental Europe. The newly appointed Australian representatives will serve industry in that country, Asia and New Zealand.

Eutectic Celebrates Open House

On hand to help celebrate the formal opening on August 20th and 21st of Eutectic Welding Alloys Corp.'s new welding service center and warehouse at 416 W. Eight Mile Rd., Detroit, Mich., were L. D. Richardson AWS and Michael Doody. Mr. Richardson, director of Eutectic's Technical Services, explained the important role of special alloys through fabrication and repair of costly tools and dies. Mr. Richardson's illustrated talk was followed by Mr. Doody's discussion of welding's applications in heavy construction and road building equipment. Mr. Doody is director of Technical Information at Eutectic.

The new warehouse-service center becomes the tenth in Eutectic's nationwide network. Erving Watnik is manager of the new installation.

ALL-STATE ENLARGES HOME OFFICE

Part of All State Welding Alloys' 5000-sq ft expansion in White Plains, N. Y., includes this improved extension of the firm's checkout area

COMING EVENTS

A Calendar of Welding Activity

AWS National Meetings

40th Annual Meeting and Seventh Welding Show:

April 6–10, 1959, Sherman Hotel, Chicago, Ill.

1959 National Fall Meeting:

Sept. 28–Oct. 2. Sheraton-Cadillac Hotel, Detroit, Mich.

ASM

October 27–31, 1958. 40th National Metal Exposition & Congress, Cleveland Public Auditorium, Cleveland, Ohio.

Midwest Welding Conference

Jan. 28–19, 1959. Illinois Institute of Technology, Chicago, Sponsored by Armour Research Foundation and AWS Chicago Section.

IAA

Mar. 9–11, 1959. Annual Meeting, Roosevelt Hotel, New Orleans, La.

Western Metal Exposition

Mar. 16–20, 1959. Eleventh Western Metal Exposition and Congress, ASM and other technical groups, Pan-Pacific Auditorium and Ambassador Hotel. Los Angeles, Calif.

INTERNATIONAL WELDING NEWS

by Gerard E. Claussen

Welding Courses for Italian Engineers

The Italian Institute of Welding[1] started their 22nd and 23rd courses on specialization in welding for industrial engineers early this year in Milan and Genoa. There were 36 graduates of this course in the two cities last year. The Institute's committee on steel filler metal has embarked on tests to determine the low-temperature impact strength of commercial types of low-hydrogen, iron-oxide, rutile and cellulose electrodes. The Mesnager specimen with U and V notches and temperatures down to − 58° F will be studied. The effect of interpass temperature will be studied with low-hydrogen electrodes. The results will be reported next March.

Milanese Professor Describes New Generator

A professor at Milan Polytechnic[2] describes an 800-cycle rotating welding generator. It is stated that the high frequency makes it possible to weld otherwise direct-current types of low-hydrogen and cellulosic electrodes on alternating current. No welding results are given. The generator consists of laminated iron stator and rotor. There are sixteen poles with exciting coils in the stator. The generator may be separately excited or self-excited. Each pole is split into two branches. The generator winding is around adjacent branches of contiguous coils. The rotor has 16 teeth which create the oscillating flux at 3000 rpm as they pass across the faces of the split poles.

Welded Design in West Germany

The June issue of the West German welding magazine[3] contains two dozen short articles, all well illustrated, showing the wide range of welded design in Germany. Among the topics discussed are cranes, turbine foundations, condensers, rolling-mill equipment, light-alloy winches, automotive bodies and fuel tanks, high-vacuum mercury rectifiers, nickel-alloy equipment and stainless-steel valve bodies. Reinforcing bars 1.42 in. diam for the concrete in a new building were gas pressure welded. A truss-type highway bridge, with a span of 160 ft, was all welded, except for the field joints. For a railway viaduct in Essen and a locomotive turntable, the box section was the basis for design. The welding of a 24-ton evaporator, made of cupro-nickel (30 Ni, 1 Mn, 1 Fe) and mild steel, involved considerable welding of dissimilar material. The steel-to-cupro-nickel joints were made with covered Monel electrodes.

The German Welding Society

The president of the German Welding Society, Dr. K. Riess,[4] describes the society's scope, organization and finances. West Germany now consumes $4^1/_2$ billion cu ft of oxygen and 82,000 tons of covered electrodes annually for welding and cutting. The society has 8000 members distributed among nine regional sections and 71 local sections. It operates eight welding institutes and 105 schools. Dues are being raised next year, at which time a single member will then pay 20 marks a year. Dues for company memberships are based on the number of welding operators employed, and amounts to 500 marks (about $125) for a firm employing 75 welders.

New Specification for Welded Steel Buildings

A review[5] of the new German specifications DIN4100 for welded steel buildings points out the differences between this latest edition and the 1934 edition. The new edition permits butt welds in tension to be designed for 100% maximum allowable base-metal stress, but only in instances when the welds are 100% X-rayed. Allowable stresses in tension and bending are 22,800 psi for mild steel (St37) and 34,200 psi for low-alloy steel (St52, 74,000 psi min yield strength). Without X-ray the allowable stresses fall to 15,700 psi for St37 and 24,200 psi for St52. The design of fillet welds under combined stresses is based on the assumption that no plastic action can be allowed and on the specification that the maximum permissible shear stress is 65% of the permissible stress in tension. The fillet strengths resulting from these computations are in close agreement with experiment.

Pipe Welding in Vertical-Down Position

The welding of butt joints in line pipe in the vertical-down position, both manual and automatic, is recommended by Hense and Scheruhn.[6] In the manual welding of pipe with a 29 in. ID and 0.37-in. wall, for example, the time to complete the joint was only about half that required in vertical-up welding. The "firecracker" principle is utilized for automatic welding by a patented process. The $^5/_{32}$-in. electrode is cut to length, bent into a semicircle and inserted in a clamp containing magnetic arc-stabilizing coils in series. Unlike the usual "firecracker" method, the electrode is not covered entirely by the clamp. Special electrodes with heavy coverings are required. For root passes, a $^5/_{32}$-in. electrode is used at 125 amp ac (100 cycles). Filling and cover passes are made at higher currents. Joints in pipe with an 0.32-in. wall and 8 in. diam are completed in three passes in 40 minutes. The welds pass X-ray inspection and tensile, impact and bend specifications.

Flame-Coated Steels in Mannheim

The Mannheim laboratory of the Germany Welding Society[7] conducted tests on welds made on mild steel treated by the flame-coating process. In this process, a solution of metal salts is spread on the flame-cleaned surface and is "burnt on" by the flame-cleaning torch. The metal salts provide additional protection against rust beyond that afforded by flame cleaning alone. Welds made with rutile-covered electrodes were unaffected by the protective coating. With low-hydrogen electrodes, inclusions occurred at the fusion line which lowered the notch-impact value, but did not lower the tensile strength or bend ductility.

Submerged-Arc Welding Fluxes

The properties of alumina-silica mixtures that affect their suitability as submerged-arc welding fluxes for steel are discussed by Conn.[8] Besides liquidus temperatures, values are given for density, viscosity and surface tension at

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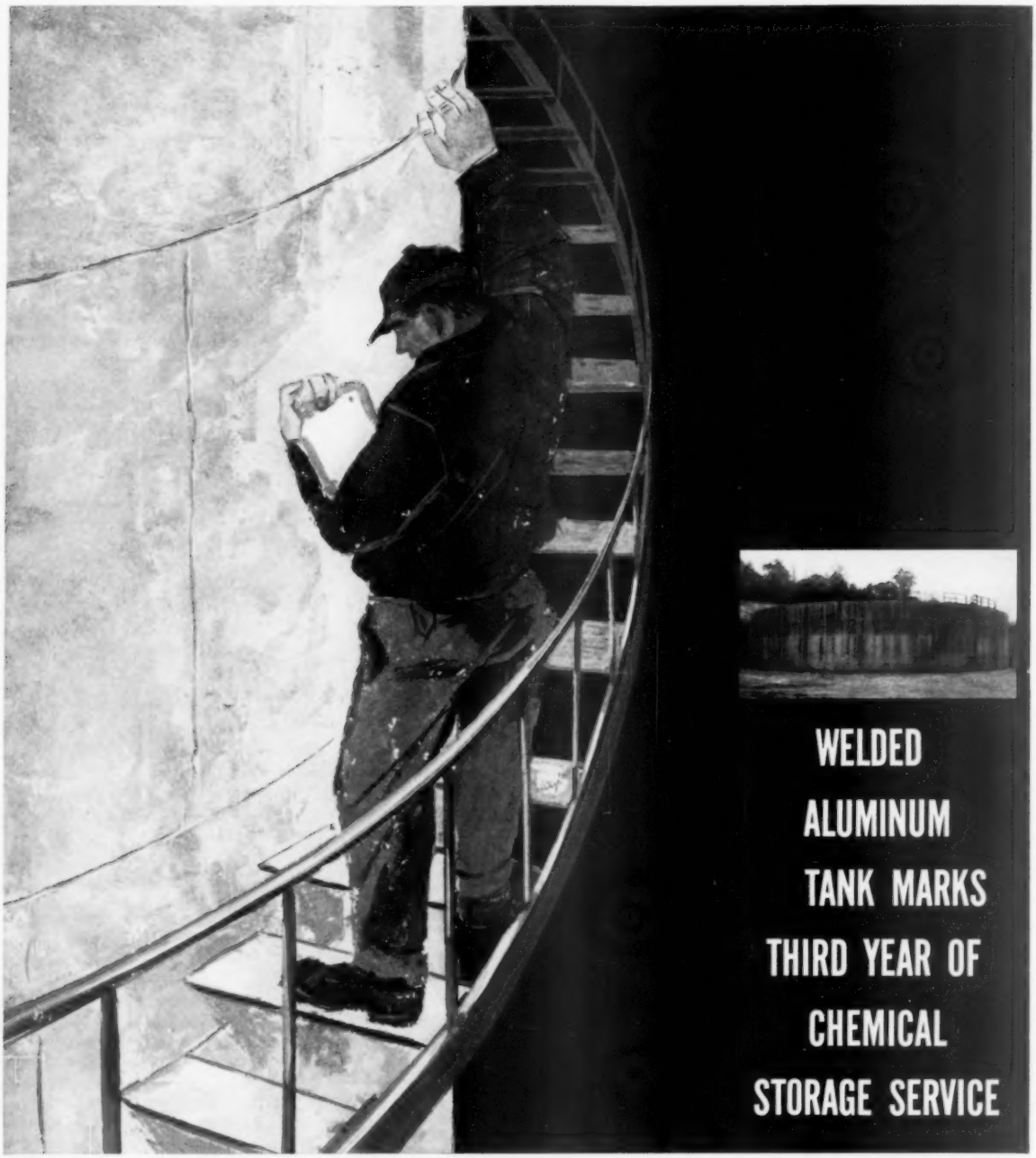

WELDED ALUMINUM TANK MARKS THIRD YEAR OF CHEMICAL STORAGE SERVICE

Mississippi River Chemical Company's all-aluminum welded tank is doing the job expected when it was built three years ago—providing trouble-free chemical storage with a minimum of maintenance.

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The giant tank was field erected by the Chicago Bridge and Iron Company. Welds were made with Alcoa welding alloy 5052 by the inert-gas, metal arc-welding process. The bottom plates are 1⅞ inches thick and courses taper to ⅜ inch at the top.

Alcoa, besides supplying the aluminum for this gigantic undertaking, rendered valuable help and guidance before and during construction. You can get the same help in welding, brazing or soldering aluminum by calling one of the Alcoa Distributors listed here. For FREE informative books and for free loan of films on joining aluminum, write: Aluminum Company of America, 1741-K Alcoa Building, Pittsburgh 19, Pa.

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welding temperatures. The effect of these properties on the rise of gas bubbles through the weld puddle is discussed. Satisfactory welds were produced by roasted mixtures containing from 40.3 to 54.2% SiO_2. It was necessary, however, to add 2 to 7% sodium or calcium fluoride to these mixtures to secure good welds.

Improvement in Fatigue Strength

Depositing a material of low elastic modulus in areas of high-stress concentration has been found to increase the fatigue strength. Matting and Rubo[9] state that for a given strain, lower stress is found in a material of low modulus than in a material of high modulus. Two materials that have been found useful in improving the fatigue strength of steel are austenitic stainless steel and aluminum bronze, having moduli of 24 and 16 million psi, respectively. The fatigue strength of a crankshaft was improved by depositing beads of austenitic steel in the fillets.

Fatigue Tests in East German Shipyard

The research and development laboratory[10] of the Warnemunde Shipyard in East Germany conducted fatigue tests on welded specimens simulating bulkhead to hull-stiffener joints. Fatigue strength was doubled by placing the welds at a distance from the area of maximum stress. Welding sequences designed to reduce shrinkage did not improve fatigue strength, nor did stress-relieving slots.

Soviet Advances

Improved Flux for Submerged-Arc Welding

The standard Russian high-manganese fused flux for submerged-arc welding[11] of mild steel tends to produce porosity in the presence of rust. Additions of ferro-alloys with or without 4% fluorspar to the molten flux in the furnace before pouring were found to reduce the sensitivity to rust. The ferro-alloys were, for example, ferrosilicon and an alloy containing 46.19% Fe, 10.3% Mn, 13.7% Si, 18% Ti, 11.35% Al, 0.45% C, 0.011% S. With 16% of the latter and 4% fluorspar added to the flux, four times as much rust could be tolerated without porosity as with the flux alone. The editors remarked that the additions are difficult to distribute uniformly in the flux, and suggest further study of the authors' proposal.

Tungsten-Electrode Welds

Two Russian articles[12] describe experimental work on temperature distribution adjacent to welds. In one article, the distribution of temperature is plotted for tungsten-electrode welds with argon protection, in Duralumin 0.02 and 0.32 in. thick. The second article shows the effect on cooling rate of immersing steel plates in flowing water while depositing a covered electrode. Compared with welding on a massive block of steel, flowing water raised the cooling rate up to 180% depending on plate thickness and rate of heat input.

Vibrator Inserted in Electro-Slag Welds

Owing to the low rate of freezing, coarse grain often is a characteristic of electro-slag welds. The insertion of a vibrator in the liquid slag has been found by Russian authors[13] to refine the grain structure and double the notch-impact value of the weld metal. The vibrator was a water-cooled block 1.58 x 0.71 in. in cross section, immersed to a depth of 1 to 1.38 in. in the slag, which was 1.18 to 1.58 in. deep over the weld puddle. The cross section of the weld was 1.18 × 4.73 in. Two 0.079-in. mild-steel welding electrodes were used, one on each side of the vibrator. It was actuated by a motor driven eccentric operating at 25 to 43 cycles per sec with a stroke of 0.07 in.

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Comparison of Electrodes for Welding Type 347

A comparison was made by Lazarev[14] between two covered electrodes for welding Type 347 stainless-steel piping for high-temperature service. The weld metal deposited by the preferred electrode contained 0.10% C, 0.34% Si, 1.44% Mn, 0.011% S, 0.021% P, 20.0% Cr, 10.3% Ni and 0.76% Cb. The ferrite content was about 4%. The weld metal from the less satisfactory electrode was almost identical, with the exception that 2.6% tungsten was substituted for the same amount of chromium. The preferred weld metal had 10 to 50% higher notch-impact value than the metal containing tungsten throughout the range from room temperature to 1290° F. Electrolysis showed that only CbC was present in the as-deposited welds, but that CbC and a carbide of Me_{23} C_6 type were present in the satisfactory weld after 10 hr at 1380° F followed by 3000 hr at 1200° F. Sigma phase was present in the unsatisfactory weld metal after this heat treatment.

Welding of Aluminum Tanks with Parallel Electrodes

The welding of two-pass butt joints in aluminum-alloy chemical tanks 10 ft in diam under flux with parallel consumable electrodes is described by Bugriy[15] of the Bolshevik plant in Kiev. The parallel electrodes are transverse to the direction of welding and make the welding operation less critical than with a single electrode. The depth of penetration was controlled by varying the spacing between the electrodes, which was generally 0.32 to 0.39 in. Electrodes were 1/16 in. diam (300–360 amp) for 1/2-in. plate. The flux contained 50% KCl_2, 20% NaCl, 30% cryolite, and had to be contained in a mold of trapezoidal cross section.

Swiss Welding Society Publishes Report

The annual report[16] of the Swiss Welding Society for 1957 refers first to the rebuilding of the welding school. During the year there were 26 courses in gas welding, 21 in arc welding and 12 in plastic welding attended by 904 students. This represented a steep rise over 1956, which in turn was well above any previous year. The society's monthly magazine contained 331 pages and was sent to 1944 members and subscribers. Society membership was 1267. The society's acetylene inspection agency performed its customary services. Exports of Swiss machinery were considerably above 1956, but there was a slackening toward the end of 1957. Steel construction and hydro-plant construction were at a high level. Consumption of oxygen, acetylene, carbide, covered electrodes and fluxes reflected the favorable economic situation. Flux for submerged-arc welding, acetylene generators, and gas welding and cutting apparatus were particularly active. In resistance welding the trend was toward three-phase connected machines and toward projection welding for mass production of sheet-metal parts.

German Welding Society Releases Book on Cast Iron

A book on the welding of cast iron[17] has been published by the German Welding Society. This is the second edition of a book published originally by the German Engineers Society in 1943. The book consists of five chapters, each written by a different author. The first chapter discusses the types of cast iron and their metallurgy. Hot welding is the subject of Chapter 2. A bare rod containing 3.0–3.6% C, 3.0% Si min, 0.5–0.8% Mn, 0.6% P max and 0.1% S max is used for gas or arc welding. A sodium-carbonate flux is used and the parts are preheated to 750–930° F.

The third chapter on cold welding strongly recommends studding, and, of course, favors nickel-alloy electrodes over mild-steel electrodes. Chapter 4 briefly discusses the welding of cast iron to steel. Cladding of the cast iron with Monel before welding with mild-steel electrodes is mentioned. Malleable cast iron is the subject of the last chapter. The European white heart type in sections up to 3/8 in. affords more latitude in welding than the black heart type, but both types require heat treatment after welding to secure the same properties as the unwelded casting.

Time and material requirements are listed for a large number of welding repairs by both hot and cold processes in gray cast iron. Alloy cast irons are not discussed.

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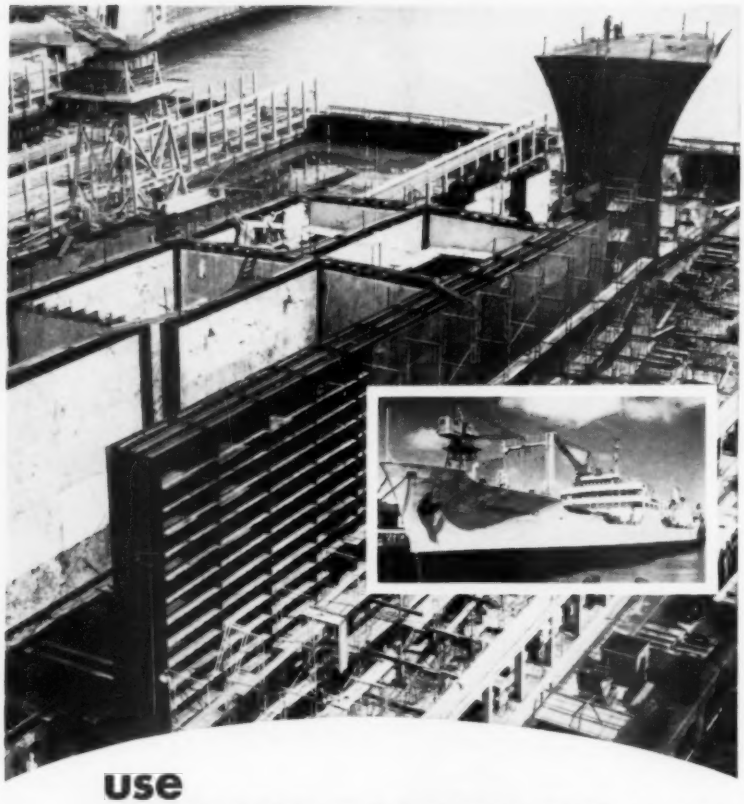
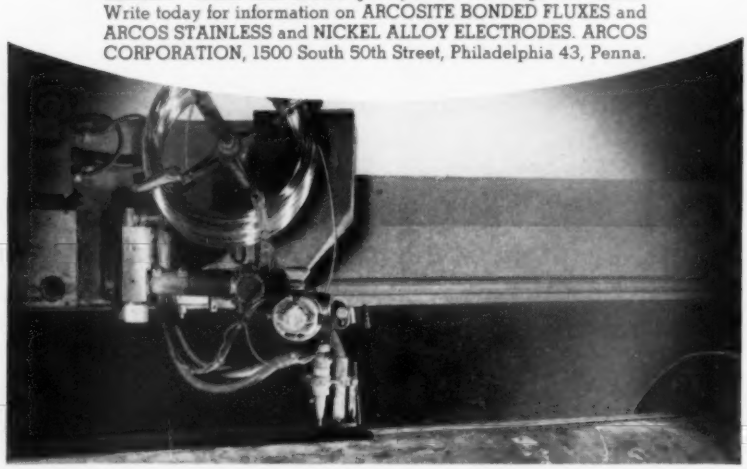


use

ARCOSITE BONDED FLUX

The SS Angelo Petri—the first of its kind—is a new wine tanker carrying 26 welded cargo tanks with a 2 million gallon bulk capacity. Especially unusual was the use of submerged arc welding on both sides of the type 316 stainless-clad steel tanks. ARCOSITE C-17 FLUX and Arcos CHROMENAR 25/20 bare wire were used to assure proper physical, corrosion resistant properties, and joint soundness. To control dilution on the stainless side, the clad side was automatically gouged slightly by carbon arc. Another unusual achievement tending to retard corrosion was the cathodic—rather than anodic quality of the submerged arc welds. Write today for information on ARCOSITE BONDED FLUXES and ARCOS STAINLESS and NICKEL ALLOY ELECTRODES. ARCOS CORPORATION, 1500 South 50th Street, Philadelphia 43, Penna.



For details, circle No. 14 on Reader Information Card

IWDA Elects Officers

At the recent annual meeting of the Independent Welding Distributors Association in Garden Grove, Calif., Willis Stanfill AWS of Welders Supply Co., Portland, Ore., was elected president for the forthcoming year. The new vice president is Ted Cox AWS of Ted Cox Welding Supplies, San Bernardino, Calif., while M. J. Andrews of Salinas, Calif., was elected secretary-treasurer.

It was also announced that the Association's next annual meeting would be held in Jackson Hole, Wyoming. The IWDA is comprised of 26 independent welding distributors from the far west, Alaska and Hawaii.

A. O. Smith Appoints Canadian Distributor

The General Welding and Industrial Supplies Ltd., 2200 Kingston Road, Toronto, Canada, has been appointed distributor in the greater Toronto industrial area for the A. O. Smith Corp.'s line of welding equipment. Co-owners of General Welding and Industrial Supplies are Messrs. James H. Robinson and J. Bruce Unroe.

G. E. Tube Opens California Office

The General Electric Co. has opened an expanded electronic tube and components sales office at 442 Peninsular Ave., San Mateo, Calif. The new office will serve equipment manufacturers in seven western states, and wholesale distributors in the San Francisco, Sacramento and Fresno marketing areas.

Belden Revises "Visarama"

Belden Manufacturing Co., Chicago 80, Ill., announces the revision of their "Welding Cable Visarama" which is a visual sales meeting designed to improve the product knowledge of the company's distributors' salesmen.

The revised "Visarama" features Belden's new neoprene cables and whip leads, as well as recent improvements in cable packaging. It also illustrates graphically the construction of Belden cables.

Financial Facts from M & T

Net sales and other income of Metal & Thermit Corp. for the three months ended June 30, 1958, amounted to $8,403,355, a decline of less than six-tenths of 1% from the $8,453,345 reported for three months ended March 31, 1958. Net sales and other income for the June quarter of 1957 amounted to $10,960,009.

Directors of M & T declared

quarterly dividends of 10¢ per share on common and 87½¢ per share on preferred stocks.

Graham Appoints Representatives

Graham Manufacturing Corp., Needham Heights, Mass., announces the appointment of three new representatives to handle the line of Graham stud-welding equipment. Wiley Welding Supply, Inc. of 2416 W. Vernon Ave., Los Angeles, will cover Southern California.

William Corns, Baywood Ave., Ross, Calif., will represent Graham in Northern California, Utah and Nevada.

Thermo Tech Products Co., 2466 S. Delaware, Denver, Colo., will handle Graham products in Colorado, Wyoming, Arizona and New Mexico, while Correll Engineering Co., 4378 Lindell Blvd., St. Louis, Mo., will extend its present coverage to include Kansas City and environs.

In addition, Graham has set up regional offices at 15 S. Austin Blvd., Chicago, and in the Tryon Building, Paramus, N. J.

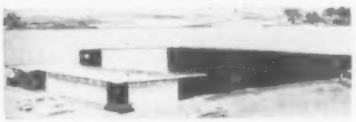
Airco Sales for Second Quarter

Sales of Air Reduction Co., Inc., for the second quarter of 1958 were $42,363,939, compared with sales of $46,815,125 during the second quarter of 1957, a decline of 9.5%, it was announced recently by John A. Hill, president of the firm. Second quarter 1958 net income was $3,185,667, compared with second quarter 1957 net income of $3,885,106, a decline of 18%.

Smith Welding Names New Agency

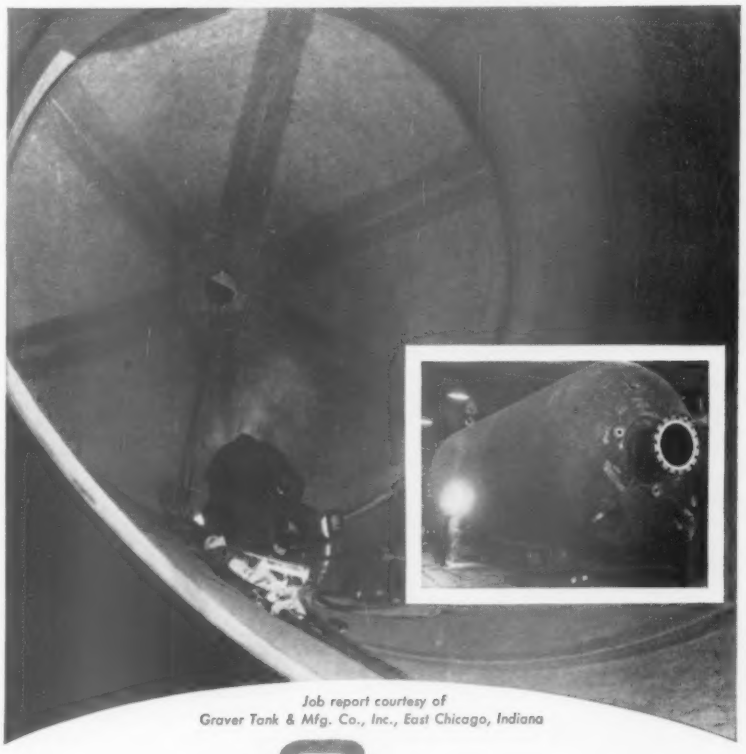
Smith Welding Equipment Corp. has appointed Kerker Peterson Hixon Hayes, Inc., Minneapolis advertising agency, to handle its advertising and public relations programs, according to L. L. McBurney, president.

EARLBECK & LANDRUM MOVES TO NEW QUARTERS



Earlbeck & Landrum, Inc., Baltimore welding distributor, recently opened this new glass and welded steel building at 8401 Pulaski Highway. The building has 70 ft of glass panels set in an all-welded structural-steel front

When stainless welds must be free of microcracks



Job report courtesy of
Graver Tank & Mfg. Co., Inc., East Chicago, Indiana

WELD WITH ARCOS

STAINLESS ELECTRODES

This 93,400-lb. 3500 cu. ft. digester is installed at Finch, Pruyn and Company, Inc., manufacturers of printing and converting papers. It converts hardwood into paper pulp using highly corrosive acids at high temperatures, and pressures of 200 psig. The digester is made of Type 316 ELC 20% stainless clad on ASTM A-212 Grade B firebox steel. To assure sound, long-life corrosion-resistant welds, three grades of Arcos CHROMEND Electrodes were used. All welding was manual. The resultant welds were completely free of micro fissures or cracks—more proof why Arcos weld metal is used so widely to combat destructive and costly corrosion. Write for an Arcos Stainless Application Chart. ARCOS CORPORATION, 1500 South 50th Street, Phila. 43, Pa.

For details, circle No. 15 on Reader Information Card

LINCOLN FOUNDATION NAMES BEST DESIGNS FOR WELDED BRIDGES

A total of $50,000 in awards was presented to the winners of a recent design competition for welded bridges in interstate and defense highways. The competition was sponsored by The James F. Lincoln Arc Welding Foundation, Cleveland, Ohio. First award of $10,000 was presented to Farland C. Bundy and Charles S. Matlock, both from the Bridge Division, Texas Highway Department, for their joint design of a 668-ft all-welded continuous plate girder bridge in Houston, Tex. Two second awards, each totaling $7500, were presented to engineers from Columbus, Ohio, and Dallas, Tex., respectively. The Ohio team of Dale C. Hoffman and Dwight H. Sparks received one of these awards for the design of a 4-span 398-ft haunched girder bridge. The other team of second place winners, Joe C. Bridgefarmer, Douglas A. Nettleton and William L. Powell, were responsible for the design of an all-welded arch bridge on the Dallas-Fort Worth Turnpike. The three design teams who shared $5000 each for third place were Emory Bond, Jr. and Gene E. Ellis; Earl D. Schwartz and Marcello H. Soto; and Costas Demos, Harry V. Lundstrom, Jr., Donn S. Robenalt and Paul M. Shepard, Jr.

Serving on the jury for the awards were Dr. E. E. Dreese of Ohio State, E. S. Elcock of the Kansas Highway Commission, Prof. T. C. Shedd of the University of Illinois, James G. Clark, and Vernon Romine of the Illinois Division of Highways.

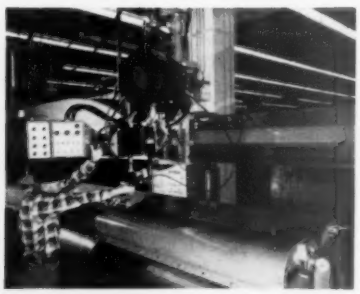
First Award in The James F. Lincoln Foundation's welded highway bridge competition was presented for the design of the above 668-ft twin span near Houston, Tex. Designers of this structure are Farland C. Bundy and Charles S. Matlock of the Texas Highway Department

The design for the above box-girder arch bridge on the Dallas-Fort Worth Turnpike won one of two Second Awards in the Lincoln competition. Three Texas engineers, Joe C. Bridgefarmer, Douglas A. Nettleton and Wm. Llewellyn Powell, collaborated to design this structure

HOBART REPRESENTATIVES ENTERTAIN PRESS AT SUMMIT MEETING

Shown enjoying the pre-banquet festivities on June 26th at the Summit Meeting of Hobart Brothers Co. in Troy, Ohio, are *(left to right)* Ted Jefferson, editor of *Welding Engineer*, Ralph Dalton of Hobart's advertising agency, Tom Dempsey, general manager of *Industry & Welding*, Bob Irving, assistant editor of THE WELDING JOURNAL, and W. H. Hobart. Some 200 welding distributors were on hand during the three-day conference of lectures and tours. The new Hobart Welding School was officially opened at this time

DIFFICULT ALLOYS JOINED AT BOEING



Built to the specifications of Boeing Airplane Co., this large Weltronic tungsten inert-gas fusion welder is being used to join titanium, stainless steel, aluminum and magnesium alloys. As shown here, the 14-ft radial beam of the welding machine has been swung into position over a 10-ft stake fixture preparatory to laying down a longitudinal weld on a curved surface

32-In. Vacuum Furnace

A new 32-in. vacuum furnace for degassing, annealing and brazing has recently been installed in the Detroit plant of Stainless Processing Division of Wall Colmonoy Corp.

The new vacuum equipment was designed for unusually low-pressure operation.

Capable of accepting parts up to 30-in. diam by $4^1/_2$ ft long, processing temperatures up to 1850° F and pressures as low as 0.01 micron can be attained. It is particularly suited for processing titanium and zirconium alloys as well as stainless steels, superalloys and so-called hard-to-braze metals.

FROM RIVETS TO WELDS

One of the 1350-lb sections in the 60-ft extensions at the Elrama Power Station, Duquesne Light Co., Elrama, Pa., is shown being raised into place for final welding. One of three welded extensions to 7-yr old riveted bases, the fabrication was completed, despite adverse weather conditions, in 10 days by McAleenan Bros. Co., of Pittsburgh. More than 48 tons of $^1/_4$-in. carbon-steel plate were used

NEOPRENE INSULATED . . .
INDESTRUCTIBLE-SHOCKPROOF
CABLE CONNECTIONS and CABLE SPLICES

for Safety-Speed-Economy

You get *all* these Advantages with the new Cam-Lok System of Neoprene Insulated Cable Connections and Splices:

- *Completely safe in any kind of weather* . . . neoprene sleeve permanently vulcanized to cable jacket—can't pull away exposing bare wire. Connections won't shatter or crack under impact of trucks or heavy plates. Resist oil and gasoline too.
- *Exclusive Quick-Disconnect* . . . Cam-Lok gives you positive lock, high conductivity cable connections, yet they can be taken apart *instantly*. Join all cable sizes without adaptors.
- *Eliminates corrosion problems* . . . watertight, vulcanized seal prevents moisture from entering cable strands . . . assures longer cable life.
- *Tapered, tight and smooth* . . . exclusive Cam-Lok tapered Connections and Splices slide over or around obstructions as easily as cable itself . . . can't pull apart . . . eliminate production "bottlenecks."
- *Economical* . . . outlast ordinary connections 3–4 times. Long-life and trouble-free performance . . . vulcanized neoprene insulation supports cable at connection and eliminates breakage.
- *Quick* . . . you can make a Cam-Lok waterproof vulcanized Cable Connection or a permanent Cable Splice in minutes on the job. No training needed to operate Cam-Lok 110 volt portable Vulcanizing Kit. Connect or splice together all cable sizes without adaptors.

Write for new Cat. #131-B or see the complete Cam-Lok line at Booth #1039, National Metal Exposition, Cleveland, Oct., 27-31.

cam-lok DIVISION

EMPIRE PRODUCTS, INC.
P. O. BOX J-98, CINCINNATI 36, OHIO

For details, circle No. 16 on Reader Information Card

PERSONNEL

Hickox Awarded Airco Fellowship at Ohio State

George K. Hickox of Columbus, Ohio, became the first recipient of a $3000 Air Reduction Fellowship in welding engineering at Ohio State University.

The fellowship was established last year by a grant from the Air Reduction Co., Inc., New York, N. Y., to encourage graduate study and research in the welding engineering field.

Mr. Hickox, who is enrolled in a combined engineering-graduate program at Ohio State, began his fifth year of study at the university this autumn. He expects to receive both his bachelor's and master's degrees in August 1959.

His research will deal with an interpretation of fusion weld quality from xeroradiographic images.

Cox Assigned by Harris Calorific

C. M. Taylor, president of the Harris Calorific Co., Cleveland, Ohio, announces the appointment of Troy G. Cox as branch manager for the company in Dallas, Tex.

He will be responsible for coordination of all marketing and selling activities relative to Harris, its distributors and dealers in the state of Texas.

Mr. Cox was formerly a technical service engineer on Harris equipment for the Harshaw Scientific Co. in Houston.

Woomer to Head Society of Mining Engineers

The Society of Mining Engineers, a constituent body of the American Institute of Mining, Metallurgical, and Petroleum Engineers, has announced the succession of Jerome W. Woomer, Pittsburgh consultant, to the post of president for one year beginning February 1959.

Haberman Named by Eutectic to Canadian Post

Mike A. Haberman has been named manager of Eutectic Welding Alloys Corp.'s office in Montreal, Canada. The Canadian subsidary, known as Eutectic Welding Alloys Co. of Canada, Ltd., is located at 3150 37th St., Ville St. Michel. Mr. Haberman, who is fluent in French, will supervise customer service and will also direct courses at the Montreal plant's "Welding Institute." A member of the Canadian Welding Society, Mr. Haberman had spent several years at Eutectic's main plant in Flushing, N. Y.

Roe Named Sales Manager for Nottingham

J. B. Nottingham & Co., Inc., engineering representatives for the Cam-Lok Division, Empire Products, Inc. and C. H. Stevens & Co. Inc., with headquarters in New York City, has appointed Walter G. Roe as Manager—Sales.

Walter G. Roe

Mr. Roe was formerly associated with the General Electric Co. in the capacity of Manager, Atlantic District, Welding Sales.

Wilbur and Jerome Named by Progressive Welder

According to an announcement by Harry S. Rose AWS, vice-president of Progressive Welder Sales Co., Pontiac, Mich., William T. Wilbur and Stephen E. Jerome have been appointed, respectively, chief engineer and factory manager of the welding equipment manufacturer.

Mr. Wilbur has compiled 18 years of experience with resistance-welding equipment, most recently in the rocket and missile fields. Mr. Jerome had been Progressive's works manager for 12 years prior to 1954.

Schaefer Fills ASM Board Vacancy

Adolph O. Schaefer, president, Pencoyd Steel and Forge Corp., Philadelphia, has accepted appointment by the Board of Trustees of the American Society for Metals to the unexpired term of secretary of the society following the recent death of founder-member William H. Eisenman, who for forty years had served as national secretary.

Boring Appointed by American Oxygen

Donn Boring has been named equipment sales manager for American Oxygen Service Corp., Harrison, N. J. As a producer of industrial, medical and scientific gases, American Oxygen serves an area within a 50-mile radius of New York City and represents many prominent equipment manufacturers.

Stachowiak Takes Simplicity Post

Simplicity Engineering Co., Durand, Mich., manufacturers of flux-reclaiming equipment and other equipment for the sand, gravel, stone, coal and ore industries, has appointed Arthur Stachowiak to the post of assistant advertising manager. A journalism graduate from Michigan State, Mr. Stachowiak was formerly employed by a Michigan newspaper, the *Flint Journal*.

Safford to Represent St. John X-Ray

C. L. Safford, Jr. of Cleveland has been appointed to represent the Califon, N. J. firm of St. John X-Ray Laboratory in Michigan, Ohio and western Pennsylvania.

OBITUARY

Lloyd A. Baldwin

Lloyd A. Baldwin died on June 30th. He was 61 years old.

Proprietor of the Baldwin Welding Works in Parsippany, N.J., Mr. Baldwin had specialized in joining difficult-to-weld metals. As a result of his death, the Baldwin Welding Works will be closed permanently.

Weldynamics*

* ARC WELDING AT WORK CUTTING COSTS

HOW YOUR NEXT JOB WILL BE HANDLED FOR LESS COST

For lowest cost, Weldynamics indicates that both AC & DC welding currents are needed to take full advantage of today's high-speed electrodes. One machine, Idealarc, fills this need . . . does the work of two welders. As a result, you need fewer machines, work scheduling is simplified, there are fewer machines standing idle.

Lincoln men, trained in Weldynamics, will show you how to apply these cost cutting advantages to your specific jobs—with the latest methods and electrodes available today.

Idealarc 180, 250, 300, 400 and 500 amp sizes. Available as AC or AC/DC welder. Can be purchased with AC only, adding DC later. Operates on single phase power. Write for Bulletins SB-1364 and SB-1343.

The World's Largest Manufacturer of Arc Welding Equipment

LINCOLN

© 1958 The Lincoln Electric Company

THE LINCOLN ELECTRIC COMPANY, DEPT. 1945 CLEVELAND 17, OHIO

For details, circle No. 17 on Reader Information Card

NEW LITERATURE

Cylinder Manifold Catalog

A new catalog, No. 14, has been published by National Welding Equipment Co., 218 Fremont St., San Francisco 5, Calif., which describes the compound-pressure design of the West Coast firm's cylinder manifolds. The manufacturer discloses in this 24-page brochure that the outstanding advantage of its new design is the elimination of soldering in all manifold assembly parts. All parts are screw assembled. Such a feature will permit distributors and consumers to carry assembly parts in stock from which various types and capacities of cylinder manifolds can be constructed with the use of two open-end wrenches.

For your free copy, circle No. 18 on Reader Information Card.

Semiautomatic Welder

A two-color 8½ × 11 illustrated 2-page brochure describing the Colmonoy "Semi-Automatic Welder" is now available from Wall Colmonoy Corp., 19345 John R. St., Detroit 3, Mich.

The brochure points out and illustrates major construction features of the new welder and lists a wide variety of typical applications in representative industries. Tube wires available for use with the Colmonoy unit are also described in the new literature.

For your free copy, circle No. 19 on Reader Information Card.

Cutting and Power Sources

Volume 9, Issue 3 of "Memco News," published by Miller Electric Mfg. Co., Inc., Appleton, Wis., devotes most of its 16 pages to the process of carbon arc-air cutting. This June-July issue gives a detailed breakdown of the process's uses in today's market together with illustrated articles showing its advantages within such plants as foundries. Power sources for use in this process are also described.

For your free copy, circle No. 20 on Reader Information Card.

Vinylite Mask Goggle

American Optical Co., Safety Products Div., Southbridge, Mass., has issued Bulletin S-7311, a 2-page folder in color, describing the company's improved Model 482A flexible mask goggle. This safety goggle has been enlarged to

provide greater area of protection and better facial fit. One-piece plastic, impact-resistant lenses, optional in clear or green shades, are included within a vinylite mask. The mask goggle is recommended for protection against flying particles.

For your free copy, circle No. 21 on Reader Information Card.

ELC Stainless-Steel Data

An 8-page revised edition of a booklet in color dealing with ELC stainless steel published by Armco Steel Corp., Middletown, Ohio, is now available for distribution. Types 304L and 316L are described as the best means of preventing harmful carbide precipitation in stainless-steel weldments. The booklet also contains chemical analyses, typical mechanical properties and illustrated applications.

For your free copy, circle No. 22 on Reader Information Card.

Accessories for Welding Platens

Acorn Iron & Supply Co., Delaware Ave. & Poplar St., Philadelphia 23, Pa., has published a new brochure describing two new accessories, a bending post and a horizontal clamp, for use with the firm's present line of welding platens or bending blocks. Acorn Iron's regular line is also described in the new literature.

For your free copy, circle No. 23 on Reader Information Card.

Case Histories in Resistance Welding

Sciaky Bros., Inc., 4915 West 67th St., Chicago, Ill., announce a new Volume 5, No. 3 of their "Resistance Welding at Work" publication.

This 12-page bulletin is the second in a series which describes resistance-welding case histories in both commercial and military fields, and including aviation. Many production advantages, and the betterment of product quality have reportedly been obtained in each of these instances through Sciaky three-phase resistance welding.

For your free copy, circle No. 24 on Reader Information Card.

Installation in Oxyacetylene Regulators

Modern Engineering Co., 3411 Pine Blvd., St. Louis 3, Mo., has issued an illustrated bulletin detailing installation instructions for new seats in welding regulators. Meco officials point out that the literature is prepared especially for welding and plant maintenance foremen.

For your free copy, circle No. 25 on Reader Information Card.

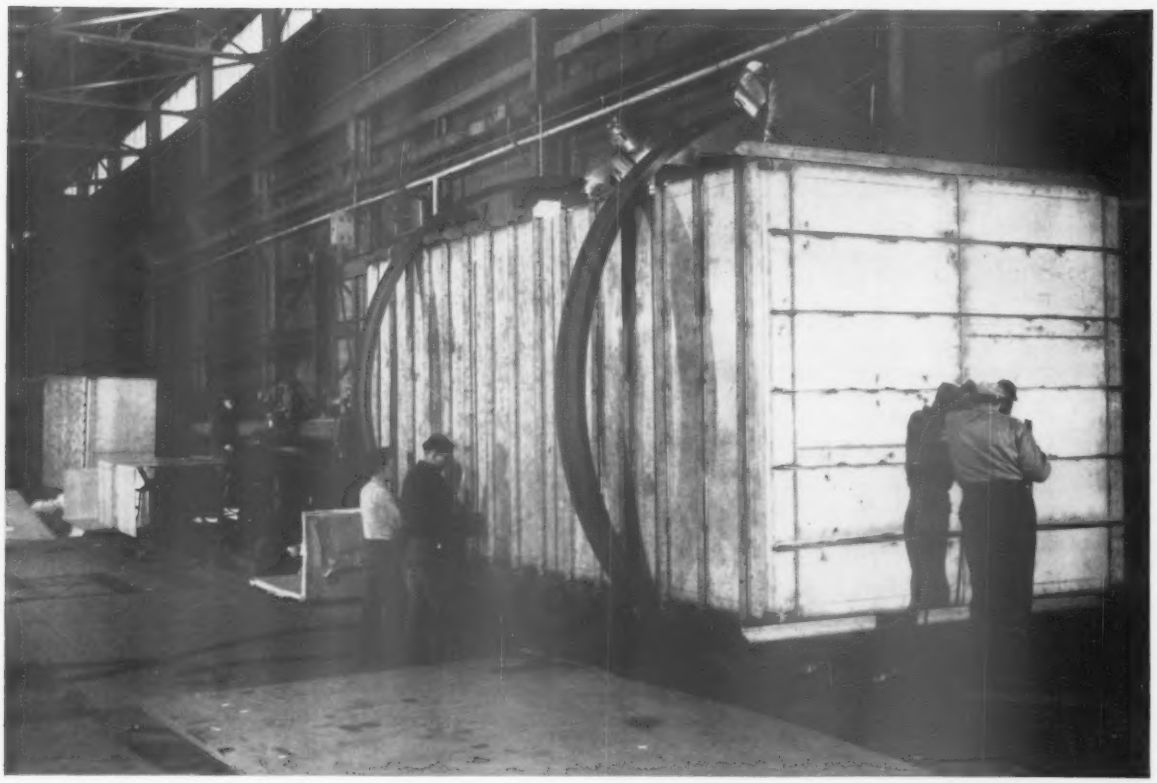
Brazing News

A four-page illustrated folder, "Brazing News No. 79," has been issued by Handy & Harman, 82 Fulton St., New York 38, N. Y. This brazing practices edition describes, in color, various instances where silver-brazing techniques of high quality were used. The folder also mentions the manufacturer's new facility at Elmonte, Calif.

For your free copy, circle No. 26 on Reader Information Card.

Powder Lance

A new 4-page folder, "Introducing the New Oxweld ACL-3 Powder Lance," from Linde Co., Division of Union Carbide Corp., 30 E. 42nd St., New York 17, N. Y., describes a newly developed tool said to be capable of slicing through concrete or metal of any thickness. Accurate control of intense heat is said to be the key to operation of the new lance. The manufacturer states that no known material—not even new, super heat-resistant materials developed for high-speed space travel—can withstand the piercing action of the new ACL-3 power lance. The booklet, Form 1153, outlines the origin, principle and scope of the powder-lancing process. It also describes cost-saving appli-



For Stainless Welds with Quality Plus . . .

CHICAGO STEEL TANK CO. specifies

ARCALOY STAINLESS STEEL ELECTRODES

The large tank illustrated above is one of several constructed by Chicago Steel Tank Co.,* Chicago, Ill., designers and fabricators of steel vessels. These vessels, which measured 8 feet wide, 9 feet high, and 20 feet long, were fabricated of type 304 stainless steel plate. The welding procedures employed were the responsibility of Henry Rouson, welding engineer, who selected Arcaloy type 308 AC-DC stainless steel electrodes for all of the manual welds.

Henry Rouson specified Arcaloy electrodes for this job, just as he has for many others. The requirements for quality at CST demand a little more than the usual high quality expected of a stainless steel electrode. Good appearance and uniformity of weld are considered extremely important.

* A Division of U. S. Industries, Inc.

Stainless steel or stainless clad material is used on critical applications for its corrosion resistance and high strength properties and the fabricator of these materials knows that electrode selection must be made with care to preserve these qualities. Alloy Rods Company has provided in Arcaloy stainless steel electrodes all of the necessary qualities for sound stainless welding, plus welding characteristics which have made this electrode a favorite of both welding management and their weldors.

There are 25 types of Arcaloy stainless steel electrodes in lime or AC-DC (titania) coatings that will improve your products . . . provide a better quality weld metal. Write for Bulletin AR-10-3 Alloy Rods Company, P. O. Box 1828, York, Pennsylvania.

Alloy Rods Company

YORK, PENNSYLVANIA • EL SEGUNDO, CALIFORNIA

Alloy Rods Co.

QUALITY WELDING ELECTRODES FOR
Stainless Steel
Mild & Low Alloy Steels
Cast Iron
Tool Steel
Bronzes & Dissimilar Metals
Hard Surfacing Electrodes & Wires

NO FINER ELECTRODES MADE . . . ANYWHERE

For details, circle No. 27 on Reader Information Card

cations in steel mills, foundries and on construction and demolition jobs.

For your free copy, circle No. 28 on Reader Information Card.

Resistance-Spot Welders

Bulletin 10-613 describes the Taylor-Winfield Corp., Warren, Ohio counting tube type of precision control for triphase electric resistance spot welders. This control is particularly suited for d-c rectifier type welders mechanically operated by air or hydraulic fluids. It provides a precise timing control for use in spot welding aluminum and magnesium alloys, low-carbon and stainless steels, hardenable steels, nickel alloys, titanium, etc. to military specifications. The power supply operates from 230 to 460 volts, 60 cycles, 3-phase.

For your free copy, circle No. 29 on Reader Information Card.

Austenitic Heat-Resistant Alloys

Bulletin TR-555 from the Tubular Products Division of the Babcock & Wilcox Co., 161 E. 42nd St., New York, N. Y., is a reprint of a technical paper entitled, "Croloy 15-15N—An Austenitic Heat Resistant Alloy for Severe Tubular Application at Elevated Temperatures." This 11-page reprint describes the involved testing program and outlines the many characteristics of B&W Croloy 15-15N. It explains why the creep-resistance and creep-rupture strengths of the alloy are reportedly superior to austenitic heat-resistant alloys presently used in the 1200 to 1500° F temperature range.

For your free copy, circle No. 31 on Reader Information Card.

Pipe Fittings

A 4-page folder in 2 colors, Bulletin TT866, describing the full line of "full-encirclement saddle" branch connections for use in the fabrication of pipe, is now available from Tube Turns, Division of Chemetron Corp., Louisville 1, Ky. Dimensional data, cyclic life and correct welding procedures are detailed in the literature. According to Tube Turns, the full-encirclement saddle provides a full 360-deg reinforcement of the pipe. The fittings are split longitudinally and are available for use with nominal pipe sizes 6 through 36 in.

For your free copy, circle No. 32 on Reader Information Card.

Electrode Conditioning Kit

A 4-page illustrated folder in color describes the contour electrode conditioning kit manufactured by SMS Corp., 8605 Livernois, Detroit 4, Mich. This particular kit, No. S-206, is recommended for users of resistance-welding machines in the aircraft and allied industries. The purpose of the new product is to maintain the exact radius and contour of resistance-welding electrode tips required in specifications. According to SMS, such conditioning will eliminate oxides, dust and other minute particles from the electrode tips.

For your free copy, circle No. 33 on Reader Information Card.

Temperature-Indicating Paper

"Thermopaper" and "Thermotube" disposable paper temperature indicators are described in a $9^1/_4 \times 3^3/_4$-in., 6-page folder issued by Paper Thermometer Co., 10 Stagg Drive, Natick, Mass. The function of the paper is to measure temperature by exhibiting an irreversible color change when subjected to predetermined temperatures with $^1/_{10}$-sec response and plus-or-minus 1% accuracy. Forty individual papers are available between the range of 100 and 490° F.

For your free copy, circle No. 34 on Reader Information Card.

Oxygen-Cutting Apparatus

A complete line of Oxweld oxygen-cutting equipment is described and illustrated in a 6-page folder, Form 1174, printed by Linde Co., Division of Union Carbide Corp., 30 E. 42nd St., New York 17, N. Y.

Torches that can be used interchangeably with oxyacetylene, oxy-propane and oxy-natural gas are described. The folder covers manual and machine-cutting equipment for use on flame-cutting jobs from sheet metal to risers 10 ft in thickness. A representative sample of the more than 400 different Oxweld nozzles is also included.

For your free copy, circle No. 35 on Reader Information Card.

D-C Rectifier Arc Welders

The manufacture of d-c rectifier-type arc welders has been announced by Weltronic Co., 19500 W. Eight Mile Rd., Detroit 41, Mich., in their technical data sheet No. 46. Available with silicon- or selenium-diode rectifiers, the new line of d-c arc welders includes 300-, 400- and 600-amp units. Operation on either metal- or tungsten-arc inert-gas-shielded welding processes is provided on all units. Such accessories as remote control, gas controls, primary contactors,

Alloys and Fluxes for Joining ALL METALS ALL METHODS
TORCH WELDING
SOLDERING • FILLING • SEALING
TORCH BRAZING
FURNACE BRAZING
ARC WELDING
GOOD WELDERS DO BETTER
with these and other
ADVANCED ALL-STATE ALLOYS
All-State
This trade-mark is reserved for the finest ALL-STATE has in FLUXES, FLUX-COATING, ALLOYS
ALL-STATE FLUX-COATED RODS HAVE ALL 3
Save Time! Money! Rework!
Nickel Silvers .... No. 11FC Brazing Rod
No. 13FC Buildup Rod
Bronzes ..... Flux-Coated, Low-Fuming Rod**
No. 41FC General Purpose Brazing Rod
Aluminum ..... No. 35FC Special Light-Coated Welding Rod
E-43 Electrode for Type 4043
E-2 Electrode for Type 1100
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ALL-STATE WELDING ALLOYS CO., INC., WHITE PLAINS, N. Y.
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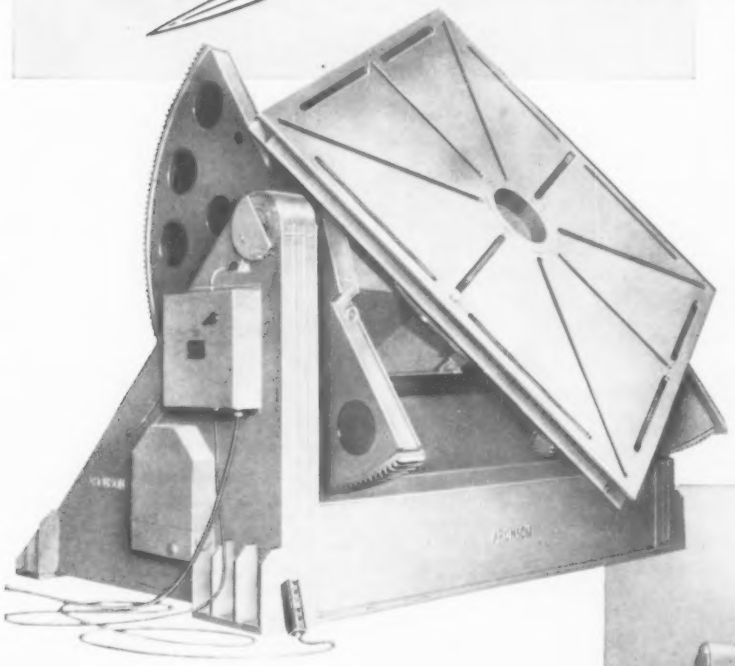
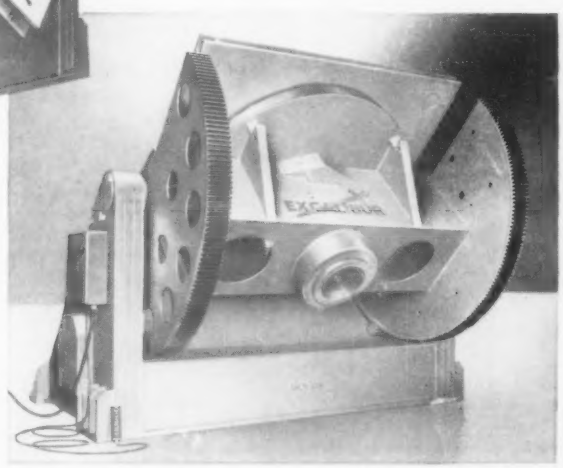
EXCALIBUR..... the HIGHEST LOAD CAPACITY Welding Positioner EVER BUILT



Aronson
MODEL G 3500



"EXCALIBUR" is rated 350,000 pounds Load Capacity with CG 12" above table and 6" off-center.

FOUR SELECTIVE VARIABLE SPEED RANGES obtained from the 4-speed gearshift transmission driven by 15 hp Varidrive afford far greater choice of variable rotation speeds. In High Gear top speed is .4 rpm adjustable to .07 rpm. This exceptionally high rotation speed permits automatic welding at high travel rate on diameters as small as eight inches! Then, for larger diameters shift into 3rd Gear and use the .23 rpm to .04 rpm range. Or, still larger work may require 2nd Gear's .13 rpm to .023 rpm range. Largest weldments are profitably rotated in Low Gear range's .08 rpm to .013 rpm.

"EXCALIBUR" is not physically tremendous, being only 88" from floor to horizontal rotation axis, which allows working both large and small weldments without needing excessive headroom and without working too high above the floor.

"EXCALIBUR" has been designed to handle almost every kind of weldment at lowest possible shop cost.

Owning "EXCALIBUR" opens production doors to you that are closed to your competitors. It is NOT a special job machine, but a Welding Positioner that will handle 90% of your jobs that are as small as a ton or so to as large as 175 tons!

Owning **"EXCALIBUR"** lets you weld automatically those jobs you now wrestle around the shop floor with the profit-eating crane and have to weld manually.

With **"EXCALIBUR"** in your list of machine tool facilities you not only can underbid competition but can assure the award of the contract because your customer will know you have the facility to handle his work.

Quality POSITIONERS by **Aronson MACHINE COMPANY**
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For details, circle No. 37 on Reader Information Card

meter panels and slope controls are also available.

For your free copy, circle No. 38 on Reader Information Card.

Straight-Wheel Grinders

Two new models of straight-wheel or aerial-type grinders are described in recent literature from the Nedco Co., 27 Jones Rd., Waltham 54, Mass. According to Nedco, these grinders are especially adapted for use with high-speed abrasive wheels on such applications as rough castings, heavy welds and surface preparation prior to welding. Both Models A-1 and A-2 are portable with free speeds of 7000 rpm. The main difference is that Model A-1 has a $1^1/_2$-hp motor, while the motor contained within Model A-2 is 2 hp.

For your free copy, circle No. 39 on Reader Information Card.

Oxygen-Cutting Machine

A 6-page folder in color describes the "Schichau-Monopol," an automatic oxygen-cutting machine, manufactured by Lumoprint, Zindler-K. G., Hamburg, Germany, and distributed in this country by Hudson Equipment Co., 515 Madison Ave., New York 22, N. Y. The illustrated literature points out that cutting by this electronically controlled unit is achieved from 6 × 15 cm photographic negatives. A special 1:10 reducing camera is used to produce these small negatives which are placed into the control panel. The manufacturer discloses that the operation is fully automatic.

For your free copy, circle No. 40 on Reader Information Card.

Liquid Zinc Coating

Subox, Inc., Fairmount Plant, Hackensack, N. J., describes in a 4-page folder in color the composition and uses of "Galvanox," a zinc-rich paint which is said to provide galvanic protection to metals. In arc welding galvanized metals, the manufacturer recommends that a single coat of the product be applied to the base and the weld metals for protection against possible corrosion.

For your free copy, Circle No. 41 on Reader Information Card.

Nickel-Base Brazing Alloy

A new nickel-base brazing alloy for high-temperature service is described in a 2-color data sheet, No. 22, from the Stainless Processing Division of Wall Colmonoy Corp., 19345 John R. St., Detroit 3, Mich. Known as Nicrobraz 50, the data sheet includes such information on the brazing alloy as available forms, nominal compositions, metallurgical and engineering properties, typical applications and brazing techniques.

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For details, circle No. 93 on Reader Information Card

Welding Fittings and Flanges

Welding fittings and flanges for 4-in. nominal pipe sizes are identified in Technical Bulletin FDC-261 published by the Welding Fittings Department, Tubular Products Division, The Babcock & Wilcox Co., Milwaukee 46, Wis. The 4-page folder lists sizes, dimensions and physical data of carbon, ferritic-alloy and stainless-steel welding fittings in addition to similar grades of forged steel flanges.

For your free copy, circle No. 43 on Reader Information Card.

Welding Fittings for 8-In. Pipe

Welding fittings and flanges for 8-in. nominal pipe sizes are listed according to size, dimensions and physical data in Technical Bulletin FDC-264 from the Welding Fittings Department, Tubular Products Division, The Babcock & Wilcox Co., Milwaukee 46, Wis.

For your free copy, circle No. 44 on Reader Information Card.

Quality Control

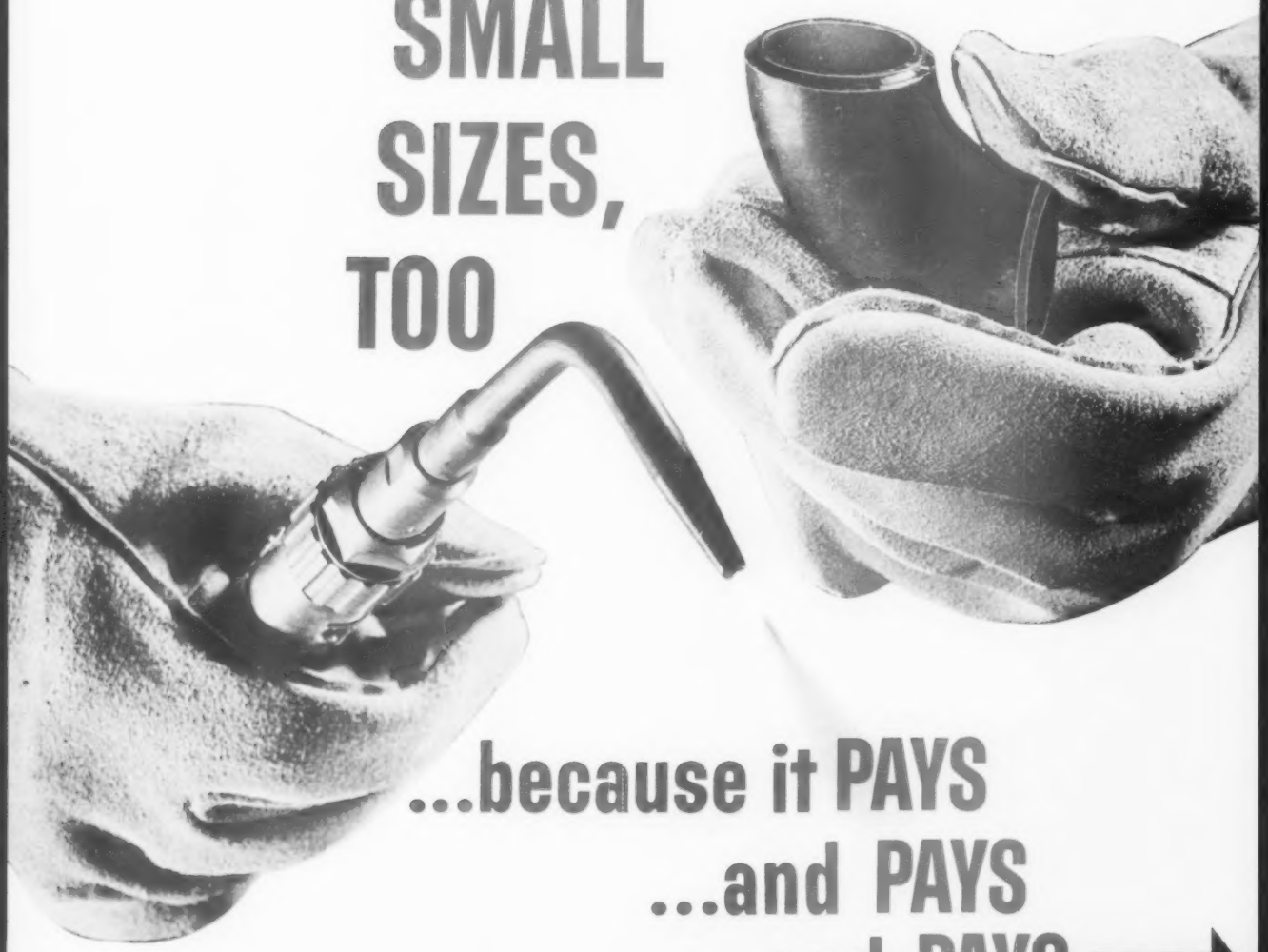
A 24-page booklet entitled "Quality

For details, circle No. 45 on Reader Information Card →

There's a trend to

WELDED PIPING IN SMALL SIZES, TOO

tt TUBE-TURN

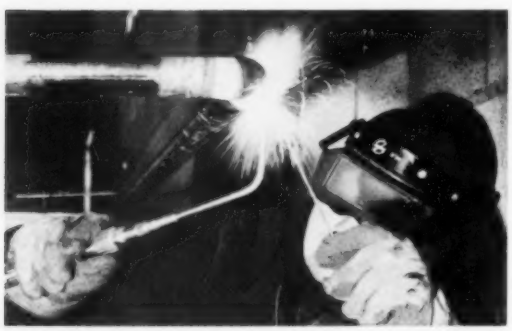


...because it PAYS
...and PAYS
...and PAYS

In small sizes . . . all sizes . . .

welded piping with TUBE-TURN FITTINGS pays off 3 ways!

SAVES ON MATERIAL. Schedule 40 pipe, butt welded, is stronger in bending and fatigue and has greater thickness for corrosion resistance than Schedule 80, threaded. Hence, welding piping can be lighter . . . can cut material costs 30-50%.



SAVES ON INSTALLATION. Butt welded joints in 1½" piping, such as school heating line shown, averages 7 minutes compared to 8 minutes for threading and tightening fitting. Tools are simple, inexpensive.

SAVES ON MAINTENANCE. Butt welded joints are permanently as strong and leakproof as the pipe itself. Photo shows ½" welded water-heat piping for shopping center . . . specified to eliminate maintenance expense.

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Control" has recently been published by the Tubular Products Division of the Babcock & Wilcox Co., Beaver Falls, Pa. This illustrated booklet, Bulletin TB-420, describes the various testing and inspection methods used during the manufacture of B&W's line of seamless and welded carbon, alloy and stainless-steel tubular products.

For your free copy, circle No. 98 on Reader Information Card.

Multi-Operator Welding System

Technical Bulletin E 15-58, printed by J. B. Nottingham & Co. Inc., 441 Lexington Ave., New York 17, N. Y., describes "The Nottingham Multi-Operator Constant Potential Welding System." The 22-page bulletin includes systematic diagrams and economical information on the system. Sections of the literature describe the system's uses, development, benefits, applications, operation, specifications and power requirements. Basically, the welding system employs a large constant-potential power source, a series of resistor banks on the secondary side and the required cables, connections and holders. Among the reported benefits of this setup are improved welding quality, reduced maintenance, reduced initial cost per arc, versatile application, compact installation, portability, long life and, ability to connect for parallel operation and availability.

For your free copy, circle No. 92 on Reader Information Card.

REVIEWS
OF NEW BOOKS

Survey of Welding in the United Kingdom

British Commonwealth Welding Conference, 469 pages, $8^1/_2$- x 11-in. hard-bound cover. Price, £5.5.0. Published by The Institute of Welding, 54 Princes Gate, London, S.W. 7, England.

This volume contains all papers presented at the British Commonwealth Welding Conference held in London in June 1957. The work itself constitutes a comprehensive and up-to-date survey of the present position of the welding processes and their main applications within the structure of the Commonwealth. Discussions of these papers are also included. Among the 60 published papers are articles on welding progress in such areas as Great Britain, Canada, India and South Africa. A glimpse into the contents of the volume reveals such diversified titles as "Welding of Rail Joints on Indian Railways," "Welding in the Petroleum Industry," "Welding in the Mining Industry," "Application of Welding in the Atomic Energy Field," "Hardfacing in Industry," "Fabrication of Welded Bridges in Canada" and "Welding Austenitic Steels for Gas-Turbine Rotors."

Constitution of Binary Alloys

Constitution of Binary Alloys by Max Hansen and Kurt P. Anderko, 1305 pages. Price, $32.50. Published by McGraw-Hill Book Co., Inc., 330 W. 42nd St., New York 36, N. Y.

Mr. Hansen is managing director, Metallgesellschaft A.G., Frankfurt-Main, Germany, while Mr. Anderko is research metallurgist at Armour Research Foundation of Illinois Institute of Technology, Chicago, Ill. These two authors collaborated on the revision and translation of the classic German work under the sponsorship of the United States Air Force through the Wright Air Development Center.

This reference book provides a source of data concerning the constitution of binary alloy systems and the crystal structure of metallic phases. Included in this latest edition are 1286 systems and 684 diagrams, and all diagrams are presented in atomic rather than weight percent. The literature dealing with the variation of lattice parameters of primary solid solutions is also considered in this present edition.

Properties of Materials

Principles of Properties of Materials by Jacob P. Frankel, 228 pages, $9^1/_4$- × $6^1/_4$-in. hard-bound cover. Price $6.00. Published by McGraw-Hill Book Co., Inc., 330 W. 42nd St., New York 36, N. Y.

This book is based on a series of lecture notes prepared for the sophomore classes on the properties of materials at the Northwestern Technological Institute. Basic knowledge of such fields as inorganic chemistry, elements of atomic theory and calculus are prerequisite for the understanding of this work.

Professor Frankel, at present a member of the Department of Engineer-

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ing's faculty at U.C.L.A., has divided the book into two main sections, physicochemical foundations and properties. The former treats elements of atoms, equilibrium, structure, cohesion and metals. The latter section deals with such areas as conductivity, heating, diffusivity, electrochemistry, elasticity, fracture and viscosity.

Handbook on Nondestructive Testing

Memorandum on Non-Destructive Methods for the Examination of Welds, 80 pages, $5^1/_2 \times 8^1/_2$ in. Price, 7/6. Published by the British Welding Research Association, 29 Park Crescent, London W.1, England.

This booklet, T.29/1, is the last in a series of three booklets, the combination of which forms BWRA's handbook on nondestructive testing. It also replaces an earlier memorandum published in March 1952. Its sections deal with the following methods: radiographic, ultrasonic, magnetic, penetrant, gas-leak, proof-test and semi-destructive. There is a glossary of terms in radiography, an appendix showing the defects in welds revealed by various examination methods and another appendix showing their applicability to the different welded joint forms.

Nondestructive Testing

Nondestructive Tests in the Field of Nuclear Energy, STP 223, 420 pages, cloth cover, 6 × 9 in., $10.00. Published by the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

The stringent requirements for practically flawless engineering materials for nuclear plants have taxed and stimulated the ingenuity of testing engineers. Particularly important have been the developments in the field of nondestructive testing as it may be applied to inspection of castings, tubing, unclad fuel element components, and clad fuel elements. Considerable development of ultrasonic and eddy current test procedures has been accomplished, and in addition work has been done on several other types of nondestructive testing.

This symposium, held in Chicago during April 1957, evolved from the meetings of an informal committee within the Atomic Energy Commission contractors dealing with the general subject of nondestructive testing. These included representatives from the national laboratories, the plutonium plants and several other AEC contractors.

There are 42 papers in the symposium covering testing of reactor components, testing of fuel assemblies, survey lectures and miscellaneous topics. Among the methods discussed are eddy current testing radiography, ultrasonic testing, X-ray diffraction and photographic methods.

German Steel Dictionary

Iron and Steel Dictionary, compiled jointly by the Iron and Steel Institute and the Verein Deutscher Eisenhüttenleute. Pocket sized 5 $^3/_8$ x 4-in. book bound in imitation leather. 272 pages. Price, £ 1.1 plus postage 6d. within the British Isles or 1 s. 4d. postage other areas. Published by Verlag Stahleisen MBH, Düsseldorf, Germany. Distributed by H. K. Lewis & Co. Ltd., 136 Gower St., London, W. C. 1, England.

This German-English/English-German dictionary contains over 7000 technical terms relating to the iron and steel industry in addition to many technical terms which are difficult to translate. Conversion tables are also included on lengths, surfaces, volumes, weights, heat quantities, pressures, weight per unit volume, energy measurements, power, heat quantity per unit of surface, volume or weight, heat conduction, temperatures, various measures, viscosity of liquids and excerpted bbreviations from the G erman Standard DIN 1301.

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For details, circle No. 48 on Reader Information Card

BOUND VOLUMES OF 1957 JOURNAL NOW AVAILABLE

Bound Volumes of THE WELDING JOURNAL for the year 1957 are available in black imitation leather covers, together with a comprehensive subject and authors index. Price $15, including postage.

This volume, comprising a total of 1260 pages in the JOURNAL and an additional 552 pages in the *Welding Research Supplement*, represents a veritable encyclopedia of information in the Welding field. Copies may be ordered through the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

For details, circle No. 47 on Reader Information Card →

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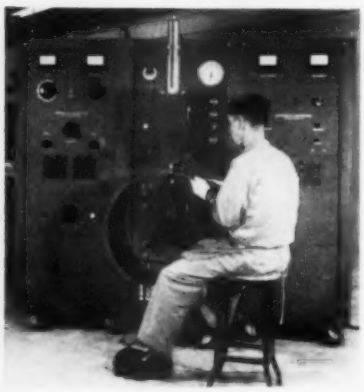
NEW PRODUCTS

2000-Watt Ultrasonic Welder

Sonobond Corp., a subsidiary of Aeroprojects, Inc., West Chester, Pa., has announced the availability of a 2000-watt production-type ultrasonic welder, Model No. W-2000-SR-57-10, for spot-welding applications. This semiportable "Sonobond" unit can be operated on 230-v circuit, consuming a maximum



of 3.5-kva power. The manufacturer points out the ease by which the unit can be operated, namely: to place the work between two sonotrodes and then to activate a foot switch, thus initiating the weld cycle automatically. The ultrasonic welder can reportedly be used to bond together, either to themselves or to other metals, aluminum, copper, nickel, stainless steels, molybdenum, tantalum and columbium.

For more details, circle No. 48 on Reader Information Card.

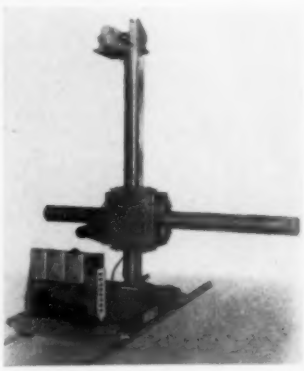
D-C Arc-Welding Machines

Three new arc-welding machines for general industrial and field use have been announced by Air Reduction Sales Co., a Division of Air Reduction Co., Inc., 150 E. 42nd St., New York 17, N. Y. The new models consist of a 450-amp "Aircomatic Fillerarc" welder designed for the consumable-electrode inert-gas-shielded welding processes; a 400- and a 500-amp Airco "Hornet" 36B motor generator for both metal-arc and inert-gas welding; and a 300- and a 400-amp "Yellow Jacket" d-c water-cooled engine-driven welders for field service.

For more details, circle No. 49 on Reader Information Card.

Two Welding Positioners

The Pandjiris Weldment Co., 5151 Northrup Ave., St. Louis, Mo., now offers the "Piper" series manipulator, along with the SAM, SWHM and RBM series.



The Piper series is a new model designed to manipulate a full automatic welding head, and is available in two standard sizes. Model 606 has 6-ft vertical arc height, and 6-ft horizontal boom travel, while the Model 808 has 8-ft dimensions.

Powerized elevation with brake motor, constant speed, push-button controlled and 360-deg manual column rotation is standard on all models. The welding power source is carried on a travel car, which operates on 36-in. track gage.

For more details, circle No. 50 on Reader Information Card.

New Packaging for Silver Alloys

Handy & Harman, 82 Fulton St., New York 36, N. Y., have developed special packaging for two of their silver-brazing alloys. "Sil-Fos" and "Easy-Flo 45" brazing alloys are now available in 20 in. lengths. The "Sil-Fos" carton contains 20 lengths totaling about 12 avoir. oz., while 17 lengths of the "Easy-Flo 45" alloy are packaged in a 5 troy oz. carton. Proper brazing procedures are outlined in a set of instructions which is inserted in each carton.

For more details, circle no. 51 on Reader Information Card.

Gasoline-Driven Welders

Miller Electric Mfg. Co. Inc., Appleton, Wis., has designed three new gasoline-engine driven welder/power plants. Model D-250, the "Roustabout," provides two d-c welding current ranges, 75 to 175 amp and 125 to 350, "The Big

Rig," reportedly delivers two welding current ranges in either ac or dc with 1 kw of d-c auxiliary power available at the same time. The third unit, Model DAH-350, known as the "Fireball," is said to incorporate in one machine an a-c, d-c welder for metal-arc or inert-gas-shielded tungsten arc welding, for use as

an a-c power plant and for 1-kw d-c power while welding.

For more details, circle No. 52 on Reader Information Card.

Build-Up Electrode

Stoody Co., Whittier, Calif., has introduced a new electrode, known as Stoody Build-Up (iron-powder coating), for restoring parts made of carbon and low-alloy steels preparatory to an overlay of surfacing alloys or for final surfacing of parts that are to be machined. For use on ac or either polarity on dc, the electrode is said to have a deposition rate of 6 lb per hr at 250 amp and registers hardnesses of R_c 26 after 2-pass weaved deposits on medium-carbon steel.

For more details, circle No. 53 on Reader Information Card.

Nickel-Base Brazing Alloy

A new nickel-base brazing alloy containing chromium and phosphorous for high-temperature service is now available from Stainless Processing Division of Wall Colmonoy Corp., 19345 John R. St., Detroit 3, Mich.

Designated Nicrobraz 50, the new brazing alloy is recommended for any application where high strength, minimum penetration of brazing alloy into base metal and low neutron absorption is required. Typical applications are honeycomb sandwich panels, thermocouples, electrical harnesses and atomic reactor heat exchangers.

Nicrobraz 50 is available as powder, plastic bonded wire, flux-powder paste or prefabricated rings.

For more details, circle No. 54 on Reader Information Card.

Foil Welding Process

Precision Welder & Flexopress Corp., Cincinnati, Ohio, announces it is manufacturing machines using the Peco foil butt-seam welding process, as exclusive licensee in U. S. and Canada under U. S.

Which do you have?

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convert the **total** fluxed portion of electrodes into **weld metal.**
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Patent No. 2,812,417. The foil-welding process has been used in European production for several years.

According to the manufacturer, the new Precision machines make smooth, nonoverlapping seam welds of dense structure and high strength. Welds have been made on 0.078-in. stock at 3 to 24 fpm. Because the Peco process requires less heat and pressure than mash welding there is less power demand and less warping of sheets. It can be used for mild steel, low-alloy, high-carbon and stainless steels.

For more details, circle No. 56 on Reader Information Card.

Air-Cooled Engine-Driven Welders

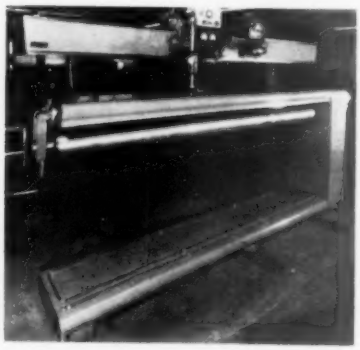
New drooping-voltage arc welders are now available from Air Reduction Sales Co., Division of Air Reduction Co. Inc., 150 E. 42nd St., New York 17, N. Y., in three types—250-amp dc, 300-amp ac, dc, and 300-amp a-c, d-c inert-gas welder. All machines provide 115/230-v, 10-kw, single phase, 60-cycle power when operated as power plants. They have 115-v, 1-kw d-c auxiliary power available for operating lights and power tools while welding.

The 250-amp d-c machine is designed for general purpose construction and maintenance welding in the field, especially pipe-line work. The 300-amp a-c, d-c machine is a remote area welder and power plant for a-c welding and d-c reverse or d-c straight polarity welding current. The 300-amp a-c, d-c "Heliwelder" is for field operations where aluminum or magnesium structural welding is involved.

For more details, circle No. 57 on Reader Information Card.

Longitudinal Welding Positioner

A longitudinal welding positioner with medium hold-down pressure has been announced by Airline Welding and Engineering, 785 N. Prairie Ave., Hawthorne, Calif. The manufacturer reports that the new unit, Model LW 10020, is for use in joining metals up to



1/4 in. in thickness in any regular configuration from flat sheet to cones or cylinders up to 30 in. ID. A feature is a special unit that reportedly activates two parallel continuous banks of flexible, level-seeking hold-down gripping "fingers" which, in turn, are said to move the two edges of the workpiece together and then hold them in position under required pressure.

For more details, circle No. 59 on Reader Information Card.

Face Shield

Welsh Manufacturing Co., 69 Magnolia St., Providence, R. I., announces its "Trojan" face shield available in clear or green acetate windows, in 4, 6 or 8 in. lengths, and in thicknesses of

0.020 and 0.040 in. The polyethylene headgear is reported to have a simple ratchet adjustment, while the windows are said to be easily installed with three positive snap fasteners.

For more details, circle No. 60 on Reader Information Card.

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MATERIAL HANDLING DEVICES

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- Factory tested at triple rated capacity.
- Will lift from horizontal or vertical position.
- Cam and Pads of case hardened tool steel.
- All operating parts replaceable when worn.
- Swinging or jerking loads will not affect grip.
- Useful for positioning in welding operations.

The HEAVIER the LOAD • • • the TIGHTER the GRIP! 3-T-17

MERRILL BROTHERS

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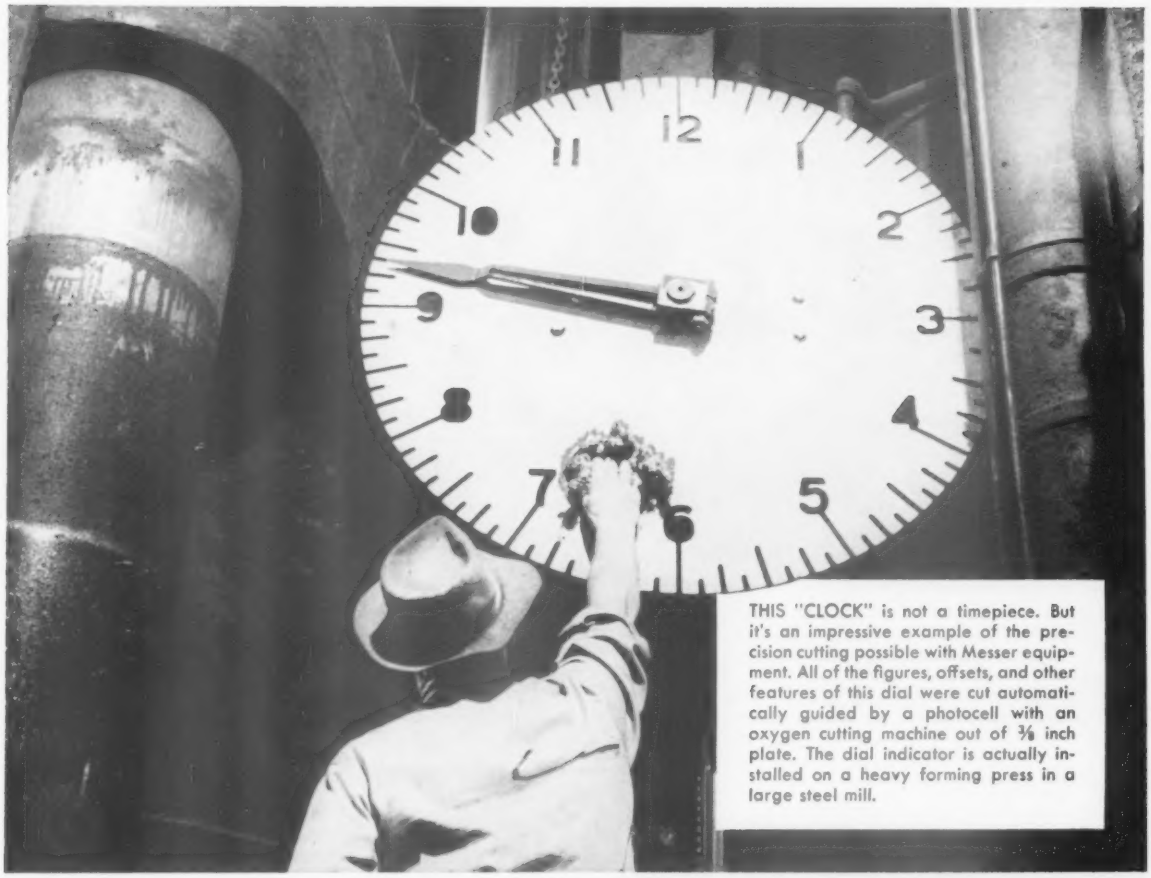
For details, circle No. 58 on Reader Information Card



THIS "CLOCK" is not a timepiece. But it's an impressive example of the precision cutting possible with Messer equipment. All of the figures, offsets, and other features of this dial were cut automatically guided by a photocell with an oxygen cutting machine out of ⅜ inch plate. The dial indicator is actually installed on a heavy forming press in a large steel mill.

Around the clock...

MESSER CUTTING MACHINES PERFORM NEW MIRACLES IN AUTOMATIC PRECISION CUTTING

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INCREASE YOUR PROFITS

Experience has shown that the Messer cutting machine versatility of design permits greater shop flexibility and the increased use of automation. The result? Lower costs, lower waste, GREATER PROFITS.

This unique oxygen cutting equipment features a completely engineered system of operation. This leads to new high standards in precision workmanship and greater accuracy.

ASK US FOR MORE DETAILS!

In steel mills, in shipyards—wherever cutting machines are used—Messer equipment can increase efficiency. It will pay you to find out *now* what Messer can offer you. Write us for full information. No obligation, of course. Messer Cutting Machines, Inc., Chrysler Building, 405 Lexington Avenue, New York 17, N.Y.

Messer Cutting Machines

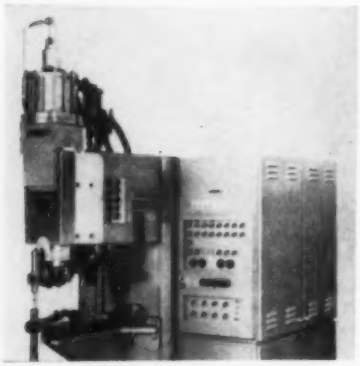
WELDING ENGINEERING SINCE 1898

For details, circle No. 61 on Reader Information Card

Maintenance in Spot Welders

A counting tube control to regulate welding timing adjustments for 3-phase d-c spot welders has been introduced by the Taylor-Winfield Corp., Warren, Ohio. It is reported that the main function of the precision control is to alert operating personnel of the area that failure occurs within the spot welder. This is indicated by a sequence of indicator lights at the top of the control. To facilitate servicing, the control also features drawer-type units that can be pulled open or completely removed from the main control panel.

For more details, circle No. 63 on Reader Information Card.



Cold Solder

"TwinWeld Cold Solder," a type of plastic adhesive, has been developed by Fyberglas Industries Division of Schramm Fiberglass Products, 3010 W. Montrose Ave., Chicago 10, Ill. The manufacturer discloses that the cold solder product assures permanently bonded applications and repairs even between such dissimilar materials as wood to metal, metal to glass and metal to metal. The cold solder is also said to adhere firmly to cement without keying and to withstand 600 ft-lb of impact psi.

For more details, circle No. 64 on Reader Information Card.

Air-Operated Butt Welder

A new air-operated butt welder, Model BW, has been designed by Alphil Spot Welder Mfg. Corp., 1058 Pacific St., Brooklyn 38, N. Y., which is said to complete up to 2500 welds per hr in semiautomatic operation. The unit is

recommended for welding wire rings, rectangulars, flats and angles, both cold- and hot-rolled materials. According to Alphil, the welder's "step-in" die permits fast alignment of light wires, and welds from $^1/_{16}$ to $^1/_2$ in. diam with the same jaw setting.

For more details, circle No. 65 on Reader Information Card.

Aluminum Soldering Flux

A new aluminum soldering flux, developed by the American Solder & Flux Co., 19th & Willard Sts., Philadelphia 40, Pa., is said to promote capillary action on aluminum. The flux may be used to join aluminum to aluminum or aluminum to other metals. The capillary action will reportedly draw the solder between two pieces of aluminum even when they are held in a vertical position. Operating temperature ranges from 600 to 675° F. Residue may be removed with water.

For more details, circle No. 66 on Reader Information Card.

Stud Welding

Shielded Stud Welding Co., 1540 Seabright Ave., Long Beach 13, Calif., reportedly has developed a means (patent pending) of stud welding sheet metal, including galvanized steel, as thin as 0.020 in. using electric-arc stud-welding equipment without backing,

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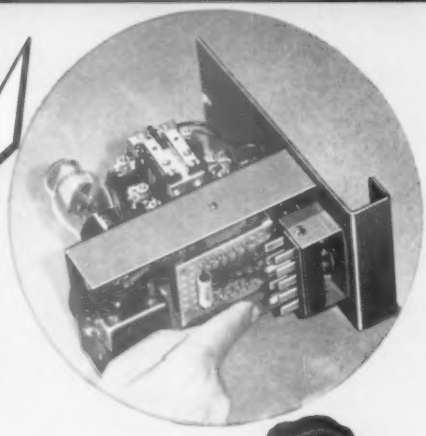
Welding Press Control illustrating simple removal of plug-in electronic timer



Plug-In TIMERS

are designed to stand up under hard industrial usage. Both timers and sequencing relays can be installed in a matter of seconds. Down time is reduced to absolute minimum during replacement. Timing circuits are fail-safe—if any tube fails to fire, circuit will be opened and welding process stopped instantly.

Plug-in relays being removed from welding press controller
Faster electrical maintenance

Plug-In RELAYS

are of special rugged industrial design and construction. Flexibility provided by plug-in feature (on both sequencing relays and timers), permits easy circuit changes without complete controller redesign.

Write for Bulletin 8991
Square D Company, 4041 N. Richards Street, Milwaukee 12, Wisconsin

SQUARE D COMPANY

For details, circle No. 67 on Reader Information Card

and without damaging the coating or the sheet. This development is said to extend the working range of the process.

For more details, circle No. 68 on Reader Information Card.

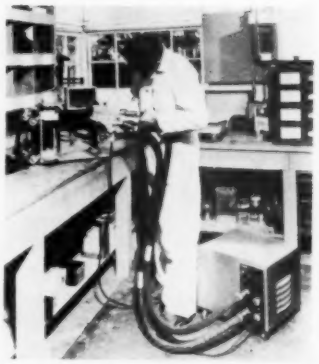
Weld Deoxidizer

A weld deoxidizer, known as Weldaluminite, has been developed by Spekaluminite Co., 100 S. Water St., Ossining, N. Y. The manufacturer discloses that this rust preventative need not be removed prior to welding; also, it improves weld quality. In addition, the product reportedly reduces porosity in carbon- and alloy-steel welding. It can be applied by brush, spray gun or dipping.

For more details, circle No. 69 on Reader Information Card.

Portable Spot-Welding Equipment

Improvements have been made on the spot welder manufactured by Adams Portable Spot Welder, 4139 S.E. 17th Ave., Portland 2, Ore., according to an announcement by T. Zilka, its new owner. Six types of spot-welding guns, each one available for water or air cooling, have been developed for use with the basic Adams transformer. Included are a pinch gun with squeeze grip; an automatic push gun with pistol grip; a push gun without handle; and a twin-spot push gun.



For more details, circle No. 70 on Reader Information Card.

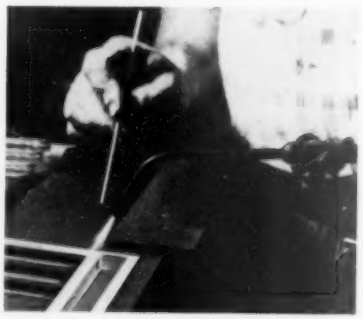
Portable Welding Screen

Frommelt Industries, P.O. Box 419, Dubuque, Iowa, have introduced their "Porto Welding Screen," a portable welding frame available in a variety of U. L. approved fabrics. A kit is provided for the screen which contains all necessary parts (except $^1/_2$-in. pipe) for quick assembly.

For more details, circle No. 71 on Reader Information Card.

Aluminum Soldering Rod

A new alloy designed for soldering aluminum, the Airco 720 Al-Solder Rod, is now available from Air Reduction Sales Co., a Division of Air Reduction Co., Inc., 150 E. 42nd St., New York 17, N. Y.



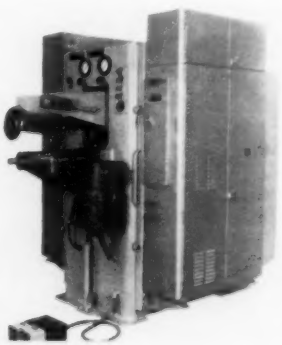
The new rod is said to provide a good color match and is clean to use, requiring no flux washing nor wire brushing. It is recommended for joining mitered aluminum windows or door sections, filling porous aluminum castings, joining aluminum air ducts, aluminum foil and aluminum tubing, and for soldering galvanized sheets.

Melting and wetting takes place 400 to 500° F below the melting point of the aluminum at a temperature of 720° F.

For more details, circle No. 72 on Reader Information Card.

Stainless Steel and Titanium Seam Welder

A special three-phase rocker-arm type steel seam welder has been developed by the Federal Machine and Welder Co., Warren, Ohio. The machine resistance seam welds stainless steels (0.012 through 0.051 in.) and titanium to titanium alloys (0.016



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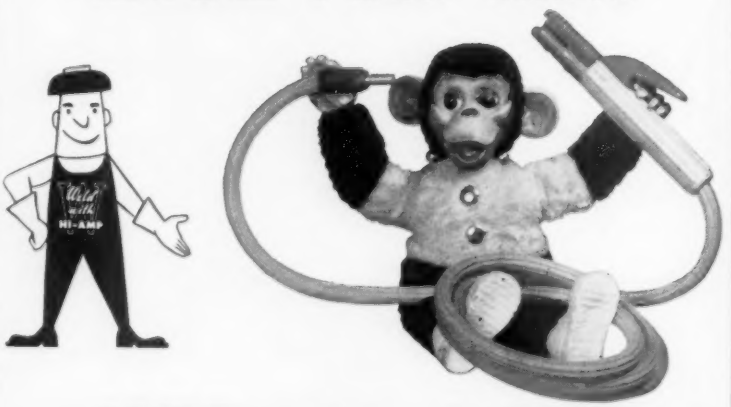

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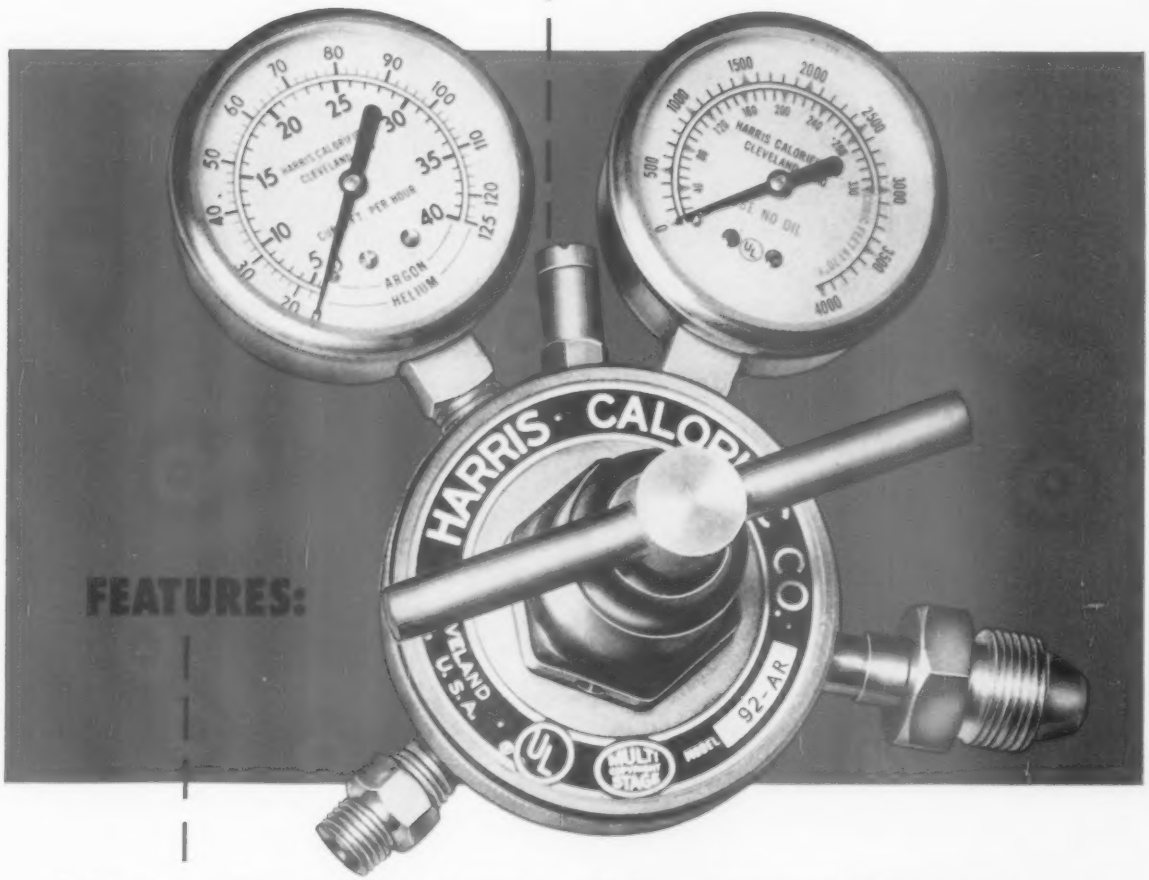

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3. May be attached to the cylinder in any position and accuracy of flow is not affected.
4. Constant flow, as originally set, is maintained as the content of the cylinder decreases.
5. No gaskets to loosen, causing loss of gas and erroneous reading of flows.
6. Price: $43.00.

These features result in greater profit, (more production per cylinder) because accuracy and uniformity of flow permit a lower flow setting.

HARRIS

HARRIS CALORIFIC CO.

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For details, circle No. 74 on Reader Information Card

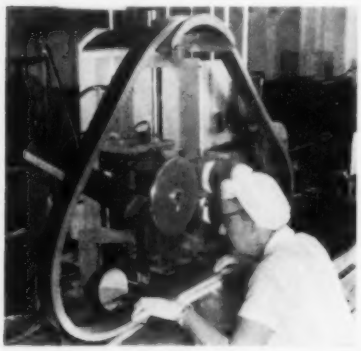
through 0.051 in.) to Air Force Navy Aeronautical Specifications.

The firing of the machine is accomplished by a precision differential switch. Drive speeds are steplessly adjusted by a d-c Thymatrol type motor drive system mounted to the lower arm. Range of drive speeds is approximately 0.5 to 4 rpm.

For more details, circle No. 75 on Reader Information Card.

Method to Form Honeycomb Structures

Foil-thin metal ribbon is reportedly formed and welded into strong, lightweight honeycomb core on a machine developed by Solar Aircraft Company, San Diego 12, Calif. Forming rollers



to the right of the machine corrugate the metal strips, which are welded layer by layer onto the circling loop of completed core. Solar has received patent rights on the machine and process. Manufacturing and sales rights have been given to Swedlow Plastics Co., Los Angeles, Calif.

For more details, circle No. 76 on Reader Information Card.

Oxygen-Cutting Unit

A German firm, Lumoprint Zindler-

K. G., of Hamburg, announces that its new oxygen-cutting machine is now being sold and serviced in the United States by the Hudson Equipment Co., 515 Madison Ave., New York 22, N. Y.

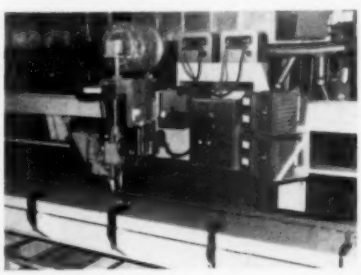
The German unit is controlled directly by 60- x 150-mm photographic glass negatives made from drawings. No other template preparation is necessary.

The burning machine has two outriggers, each equipped with up to three burning heads. According to the manufacturer, tolerances of 0.040 to 0.060 in. in 32 ft are regularly maintained.

For more details, circle No. 78 on Reader Information Card.

Automatic Surfacing Unit

Automatic Welding Co., P. O. Box 331, Waukesha, Wis., has developed an automatic rail-rebuilding unit for the surfacing of crawler tractor parts, known as the Twin Track-O-Matic. The machine features two high-frequency d-c welding heads, a 41½-ft long work table which provides 360-



deg rotation and a rotating-type control that contains a photoelectric eye to assure that the arc follows the proper sequence. A common pattern, reportedly covering all types and sizes of crawler rails, is used to ensure the function of the aforementioned control.

For more details, circle No. 79 on Reader Information Card.

Portable Spot Welder

Peer, Inc., Benton Harbor, Mich., has developed a 24-lb portable spot welder for use in joining mild and stainless steels, galvanized iron and terne

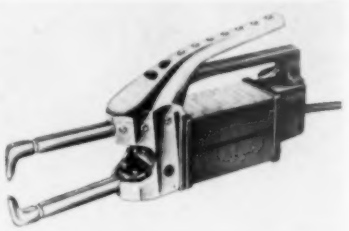


plate. Known as the Rex Junior, the unit is manufactured in either 110- or 220-v models. Automatic weld times are available. Manual timers are standard equipment.

For more details, circle No. 80 on Reader Information Card.

28-lb Spot Welder

A 28-lb spot welder, available in air- or water-cooled models, has been designed by the Merit Co., 2125 W. Rice St., Chicago 22, Ill. Known as the Merit Welder, the unit is 8⅝ in. high and 18½ in. long. Features include an automatic electronic timer and contractor, welding capacity of 3/16 in. on combined thicknesses and linkage device which permits zero to 1000-lb variable tip pressure.

For more details, circle No. 81 on Reader Information Card.

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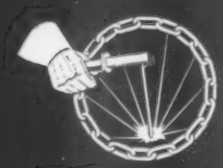

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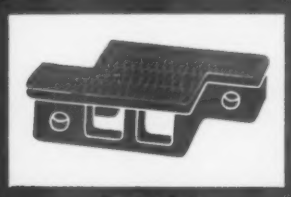

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Ditcher Rollers
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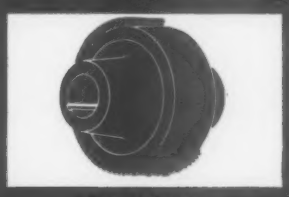
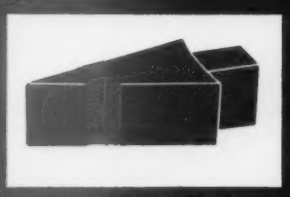


Shovel Rollers
TUBE-ALLOY 258



Shovel Bucket Teeth
TUBE-ALLOY 218

Copper-Brazing Alloys

American Brazing Alloys Co., P. O. Box 11, Pelham, N. Y., has introduced a 93% copper-7% phosphorous brazing alloy, No. 211, for joining copper to copper alloys. According to the manufacturer, the new brazing alloy does not require flux, and it is reported to have a 1300° F melting point and a 1350 to 1550° F brazing range.

For more details, circle No. 83 on Reader Information Card.

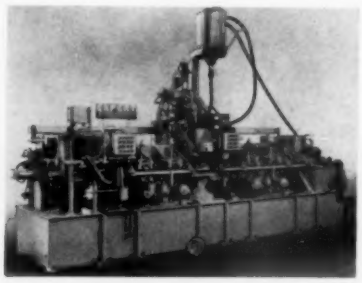
Stud Welding on Stainless Steel

The Graham Mfg. Corp., Needham Heights, Mass., announces stud-welding apparatus designed for thin-gage stainless-steel joining applications. According to the manufacturer, the equipment has the advantage of not burning through the opposite side of the metal, thus eliminating the need to grind and polish after welding.

For more details, circle No. 85 on Reader Information Card.

Automated Welding

A new Expert 10-station in-line transfer automated welding machine that combines assembly, welding and heat-treating operations in the production of disk and hub assembleis is now available from Expert Welding Machine Division, Expert Die & Tool Co., 17144 Mt. Elliott Ave., Detroit 12, Mich.



The machine reportedly press assembles two carbon-steel transmission parts (disk and hub), preheats and welds the assembled parts and heat treats the welded assembly in one continuous operation. Transmission parts are produced on this machine at a rate of 120 assemblies per hr.

For more details, circle No. 86 on Reader Information Card.

Silver-Brazing Flux

Aircosil flux, for silver brazing stainless, mild steel, copper, brass and a wide range of alloys, is now available from Air Reduction Sales Co., a Division of Air Reduction Co., Inc., 150 E. 42nd St., New York 17, N. Y., in a new 12-oz. plastic "squeeze bottle."

With the "squeeze bottle" users can direct the silver-brazing flux exactly where it is needed. The top is removable, permitting the bottle to be refilled or water to be added.

For more details, circle No. 87 on Reader Information Card.

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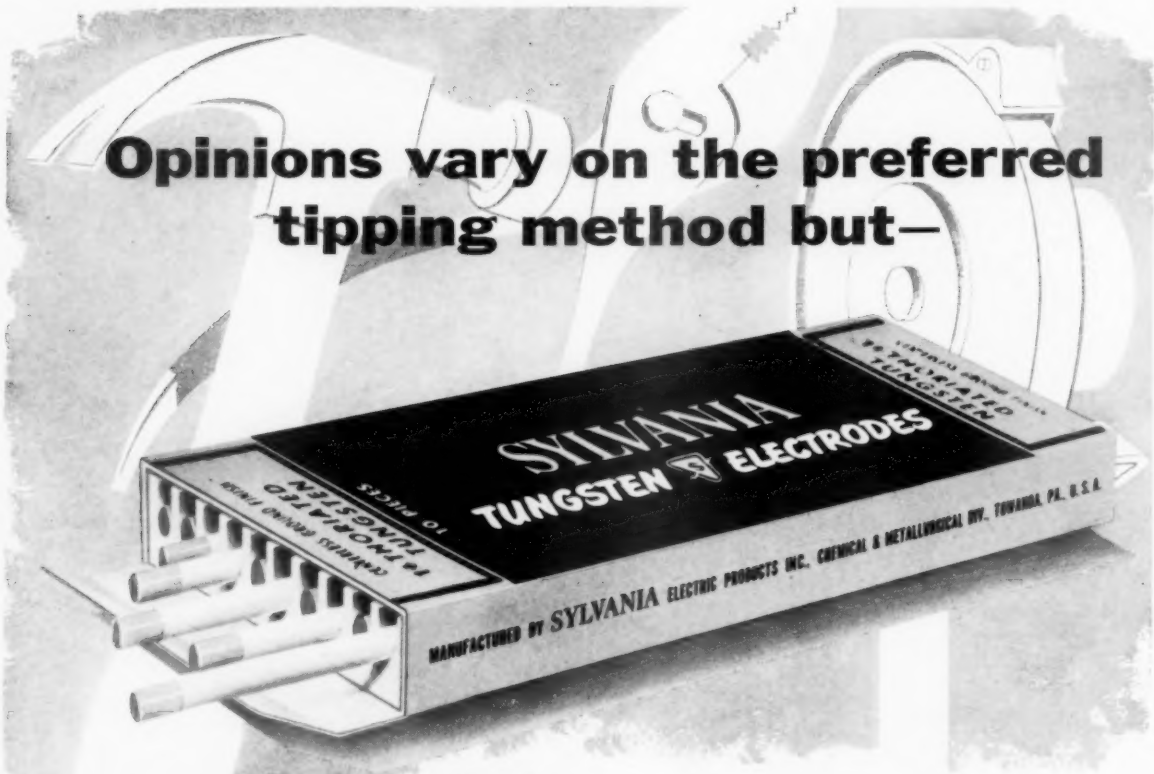
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22	47	72	97	122	147
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RESIDUAL STRESSES IN WELDED TITANIUM PLATES

Effects of plate dimensions, preheat and cold treatment on residual weld stresses are among the factors investigated by the authors

BY E. F. NIPPES AND W. F. SAVAGE

SUMMARY. The magnitude and type of residual stresses in welded titanium plates were determined by the subdivision technique employing electrical-resistance strain gages. Commercially pure titanium plate and 7%-manganese titanium-alloy plate, 5/8 in. thick, were investigated, welded in both cases with commercially pure titanium filler wire utilizing the inert-gas-shielded consumable-electrode arc process. The investigation observed and determined (1) the effect of plate dimensions on the residual stresses produced by arc welding commercially pure and alloyed titanium plate; (2) the effect of preheat on the magnitude of longitudinal and transverse residual weld stresses in the alloyed plate; (3) the effects of cold treatment on the weld stresses in commercially pure titanium plate; and (4) weld cracking in the 7%-Mn alloy material.

Introduction

Residual stresses arising from metal-arc welding may markedly affect the performance of large welded structures. Therefore, the determination of the magnitude and direction of residual stresses in weldments have long been of considerable interest. The development of the electrical-resistance strain gage provided investigators with a reliable means of studying these stresses, and suitable techniques have been previously reported in the literature.[1, 2]

Briefly, the usual technique involves: (1) cementing the strain gages to the plates after completion of the welding operation; (2) reading and recording the original resistance of each strain gage; (3) subdividing the plates in order to free the portion of the plate containing the strain gage from the restraint of the surrounding plate; (4) reading and recording the resistance of each gage after subdividing the plate; (5) calculating, from the change in resistance of each strain gage, the magnitude and direction of the relaxation strain at each gage location; and (6) converting the measured strain values to stresses.

The effect of welding variables, plate dimensions, preheat and other factors on the residual-stress pattern have been studied[1, 2] for steel weldments, but the residual-stress patterns produced by arc welding titanium and titanium-alloy plate have not been reported.

E. F. Nippes and W. F. Savage are associated with the Department of Metallurgical Engineering at Rensselaer Polytechnic Institute, Troy, N. Y.

Table 1—Material Description for the Commercially Pure Titanium Plate

Designation—Ti 75A, commercially pure titanium
Heat no.—M1811D
Condition—as rolled
Dimensions—5/8 x 36 x 96 in.
Chemical analysis
C —0.031%
Fe—0.075%
N —0.022%
Ti—approx. 99.40%

Mechanical properties	Test 1	Test 2
Yield strength, psi	65,130	79,060
Ultimate tensile strength, psi	87,060	88,530
Elongation, % in 2 in.	23.4	22.3
Brinell hardness	202	...
Room temperature bend angle	180 deg at 1T radius 160 deg at 2T radius	

Table 2—Material Description for the 7%-Manganese Titanium-Alloy Plate

Designation—RC-130
Heat no.—AW3936T
Condition—annealed
Dimensions—5/8 x 36 x 96 in.

Chemical analysis*	Producer	Watertown Arsenal
C	0.1%	0.04
Fe	...	0.17
N	0.027	0.042
Mn	7.09	6.24
O	...	0.091
H	...	0.0080

Mechanical properties
Yield strength, psi—94,000
Ultimate tensile strength, psi—124,400
Elongation, % in 2 in.—18.3
Reduction in area, %—28.5

* Data headed Producer are taken from mill analysis. Data headed Watertown Arsenal were obtained from check analysis of drillings from the plate.

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Table 3—Material Description for Welding Wire Used

Designation—Ti 75A, commercially pure titanium
Heat no.—M 417
Wire diameter—1/16 in.

Chemical analysis

Wire	Weld deposit in 7%-Mn Plate
C —0.07%	C —0.076%
Fe—0.08%	Fe —0.13%
N —0.060%	N —0.025%
O —0.147%	Mn—3.84%
H —0.021%	

Mechanical properties of deposited metal

	In commercially pure titanium plate		In 7%-Mn titanium-alloy plate	
Ultimate tensile strength, psi	89,200	Test 1	137,000	Test 1
	89,250	Test 2	130,500	Test 2
Yield strength, psi with 0.2% offset	81,400	Test 1	135,000	Test 1
	87,600	Test 2	129,500	Test 2
With 0.1% offset	75,600	Test 1	125,200	Test 1
	81,600	Test 2	126,700	Test 2
With 0.01% offset	66,700	Test 1	100,400	Test 1
	74,500	Test 2	118,000	Test 2
Reduction in area, %	24.6	Test 1	24.6	Test 1
	24.6	Test 2	24.6	Test 2
Elongation in 1 in., %	12.15	Test 1	5.74	Test 1
	10.93	Test 2	7.47	Test 2

Object

The objects of the present investigation were (1) to determine the effect of plate dimensions on the residual stresses produced by arc welding commercially pure and alloyed titanium plate; (2) to determine the effect of preheat on the magnitude of longitudinal and transverse residual weld stresses in the alloyed plate; and (3) to observe the effects of cold treatment on the weld stresses in commercially pure titanium plate.

Material

The pertinent descriptive material characteristics for the commercially pure titanium plate and the 7%-manganese titanium-alloy plate used in this investigation are summarized in Tables 1 and 2, respectively. Table 3 summarizes the material characteristics for the commercially pure titanium filler wire used in this investigation. Included in Table 3 are the results of tensile tests performed with all-weld-metal specimens machined from deposits in both the commercially pure titanium plate and the 7%-Mn titanium-alloy plate. The chemical analysis of the deposit in the 7%-Mn alloy plate has also been included for comparison with the wire composition, and it will be noted that the Mn content was increased by dilution to 3.84%.

Procedure

Plate Preparation

Specimens of the required size were machined from the 5/8-in. plates in such a manner that the welding direction would be parallel to the major rolling direction. The edges to be welded were then machined to provide double-vee butt joints with 60-deg included angles.

Run-off tabs were tack welded to the ends of the grooves as shown in Fig. 1 using inert-gas-shielded arc welding. A 1/16-in. thoriated-tungsten electrode, ground to a point, was employed with straight polarity d-c current and 75 cfh of argon. A gas backing was utilized also with a flow rate of 75 cfh.

No filler metal was added when tack welding the run-off tabs on the commercially pure titanium plate, and the depth of penetration was reduced to the minimum required to secure the run-off tabs

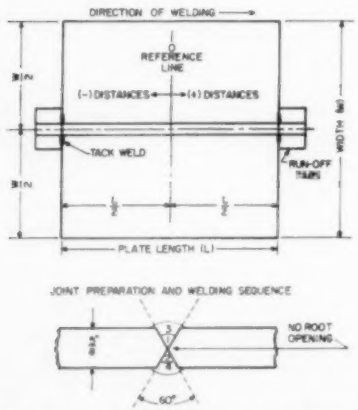

Fig. 1 General plate layout, joint preparation and welding sequence

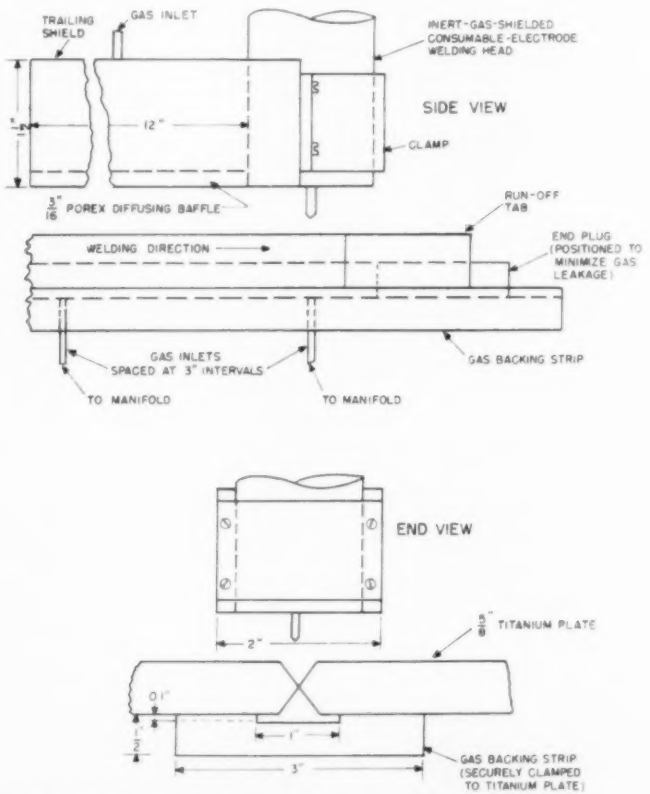

Fig. 2 Details of trailing shield and gas-backing setup

to the weld specimens. Commercially pure titanium filler wire was added to the fusion zone when attaching the run-off tabs to the 7%-Mn alloy plates in order to obtain a ductile weld.

Welding Procedure

All welding was done with an inert-gas-shielded consumable-electrode welding machine mounted on an adjustable-speed, electrically driven travel carriage. The welding head was maintained normal to the plate surface and was provided with a 12-in. long trailing shield, and gas backing was employed to protect the underside of the weld. The details of the setup for the trailing shield and the gas backing are shown in Fig. 2. Gas flow in both the trailing shield and the backing strip was maintained at 65 cfh throughout the investigation. Radiographs of welds made with various mixtures of shielding gases revealed that supplying the welding torch with a gas mixture of 40 cfh of argon and 20 cfh of helium minimized the amount of porosity in the weld.

Four passes were utilized in making each weld, sequenced as shown in Fig. 1. Continuous records of arc voltage, arc current and arc power were obtained for each weld pass. Table 4 summarizes the significant welding variables used throughout the investigation.

A total of 16 welds was made, 9 in the commercially pure titanium, and 7 in the 7%-Mn alloy. Tables 5 and 6 summarize the dimensions of the welded specimens after joining for the commercially pure titanium and for the 7%-Mn alloy, respectively.

The surface of each bead was wire brushed after it had been deposited and the next pass was started as soon as the plate temperature had dropped to 150° F.

Table 4—Summary of Welding Conditions

Process—inert-gas-shielded consumable-electrode
Filler metal—1/16-in. Ti-75 wire (see Table 3)
Shielding gas
  Trailing shield—Argon—65 cfh
  Gas backing—Argon—65 cfh
  Torch—Argon—40 cfh and Helium 20 cfh
Power supply—dc, reverse polarity, drooping characteristic
Arc voltage—28 v
Arc current—350 amp
Travel speed—20 ipm
Wire feed speed—5.65 ips = 339 ipm
Number of passes—4
Joint geometry—60-deg included angle, double-vee
Initial plate temperature—75° F
Interpass temperature—150° F

Table 5—Summary of Dimensions of Welded Specimens, Commercially Pure Titanium

Plate no.	*Length, in.**	*Width, in.*
6	24	20
4	20	20
5	20	20
3	16	20
2	14	20
1	10	20
15	16	16
16	16	10
12†	20	16

* The dimension measured parallel to the weld is always identified as the length.

† This weld was subjected to −77° F for 65.5 hr after welding.

Table 6—Summary of Dimensions of Welded Specimens, 7%-Manganese Titanium Alloy

Plate no.	*Length, in.**	*Width, in.*
10	24	20
9	24	20
8	20	20
7	16	20
13	16	16
14	16	10
11†	20	16

* The dimension measured parallel to the weld is always identified as the length.

† This weld was made with 300° F preheat.

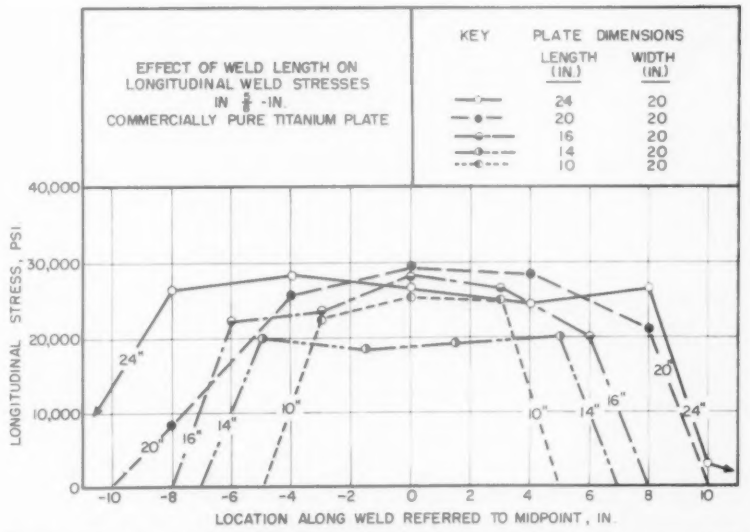

Fig. 3 Effect of weld length on longitudinal weld stresses in 5/8-in. commercially pure titanium plate

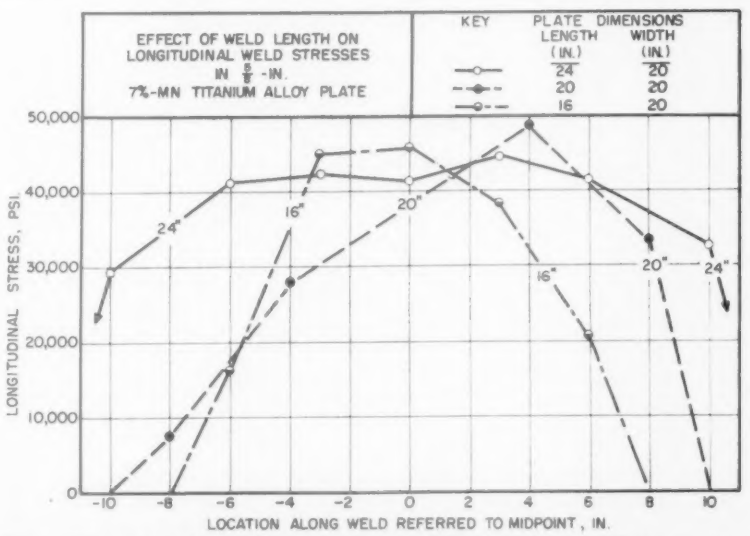

Fig. 4 Effect of weld length on longitudinal weld stresses in 5/8-in. 7%-Mn titanium-alloy plate

Procedure for Attaching Strain Gages

Four methods of surface preparation were studied in order to determine which provided the most satisfactory surface condition for attaching the strain gages. The four methods studied were (1) as-milled surface; (2) ground with 6-x 1-x $^1/_2$-in. cup wheel, silicon carbide type, medium grade, medium structure, resinoid bonded, wheel speed 4500 rpm; (3) ground with 10-in. diam, 16-grit, paper disk at 500 rpm; and (4) ground with 10-in. diam, 60-grit, paper disk at 500 rpm.

Of the above methods, No. 2, the cup-wheel grinding operation, was found to produce the best surface for cementing the strain gages to the titanium.

The following procedure was adopted for attaching the strain gages:

1. Mill the excess metal, or weld reinforcement, to within a few thousandths of an inch of the plate surface.
2. Grind off the remaining reinforcement flush with the plate surface with the cup wheel.
3. Radiograph the weld to reveal any internal flaws or porosity.
4. Check surfaces of weld for cracks with a dye penetrant.
5. Clean with toluene, followed by cleaning with acetone, and finally with ethyl acetate.
6. Attach strain gages with unthinned, tube-Duco cement.
7. Dry according to the recommendations of the manufacturer of the gages.
8. Coat gages with melted ceresin wax to exclude all moisture.

Two types of strain-gage rosettes were used:

1. Type AR-1 strain-gage rosettes, composed of three $^{13}/_{16}$-in. gage length windings oriented 45 deg apart. This type of gage was used only at positions near the ends of the weld bead to verify that the principal stresses were parallel to and perpendicular to the weld bead.
2. Type AX-5 strain-gage rosettes, composed of two $^1/_2$-in. gage length windings oriented at 90 deg. This type of gage was used at all other locations.

Type AR-1 strain gages were located two inches from each end of the welds on both the top and bottom sides of the 16-, 20- and 24-in. long welded specimens. Type AX-1 gages were mounted on both the top and bottom sides along the intervening length of the welds at intervals of not less than 3 in. or greater than 4 in. Similar locating procedure was employed with the 10- and 14-in. long welded specimens except that the type AX-1 gages were used at all locations. Every effort was made in mounting the gages to align the gage length of the strain-gage element with the centerline of the weld as exactly as possible.

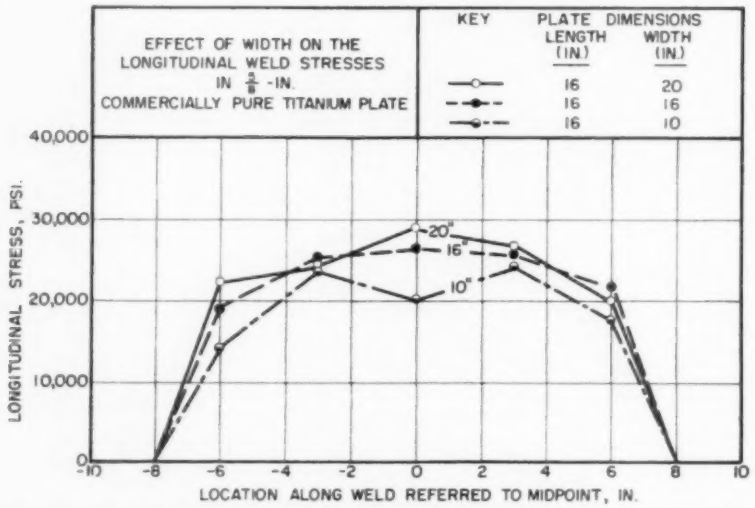

Fig. 5 Effect of width on the longitudinal weld stresses in $^5/_8$-in. commercially pure titanium plate

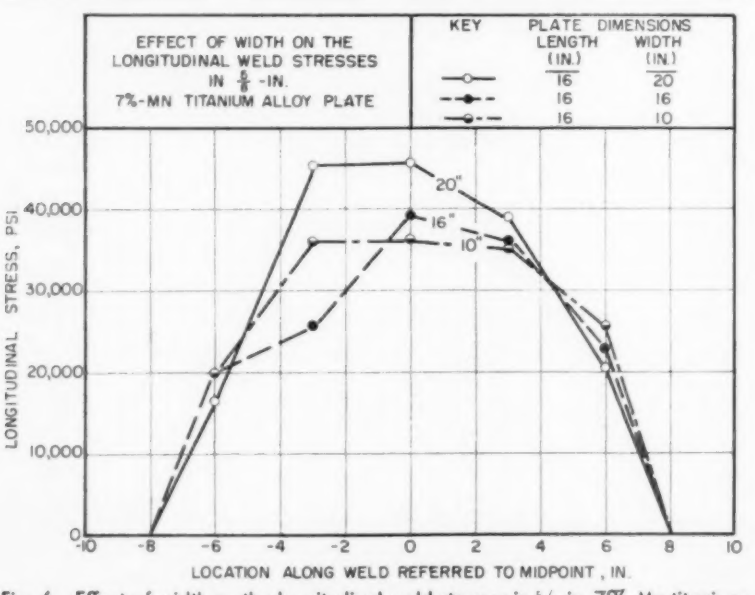

Fig. 6 Effect of width on the longitudinal weld stresses in $^5/_8$-in. 7%-Mn titanium-alloy plate

Procedure for Determining Residual Stresses

After the strain gages were mounted and waterproofed, the plates were allowed to stand at room temperature for at least 24 hr before zero readings were taken of the gages. Four readings of the initial resistance of each gage were then taken with a strain indicator. In order to make sure that the resistance values had stabilized, two of the four readings on each gage were separated by a time interval of at least 24 hr.

After the initial or zero readings were completed, the plates were subdivided on a liquid-cooled abrasive-cutoff machine. The first two cuts on each plate were made parallel to the weld at a distance of 1 in. on either side of the weld centerline. The 2-in. wide strip obtained in this fashion contained all the gages, and was then subdivided by making transverse cuts to free a series of specimens each with a strain gage on the top and bottom surface.

After subdividing the plate, four additional readings were obtained from each gage, two of the four being separated in each case by a time interval of at least 24 hr.

Since the strain indicator used was calibrated directly in terms of strain in microinches per inch, the strains accompanying the subdivision operation were thus readily obtained by subtracting the above readings from the initial or zero readings.

The direction of the principal stresses was determined from strategically located strain rosettes, and the magnitudes of the principal stresses were calculated from the principal strains by means of the following equations:

$$\sigma_x = \frac{E}{1-\gamma^2}(\epsilon_x + \gamma\epsilon_y) \quad (1)$$

$$\sigma_y = \frac{E}{1-\gamma^2}(\epsilon_y + \gamma\epsilon_x) \quad (2)$$

where

σ_x = stress in the x direction.
σ_y = stress in the y direction.
ϵ_x = strain in the x direction.
ϵ_y = strain in the y direction.
E = Young's modulus of elasticity = 16.1×10^6 psi.
γ = Poissons ratio = 0.328.

The calculation of stresses was facilitated by the use of an appropriate graphical solution. Stress calculations were made from strains measured on one surface of the plate, repeated for strains measured on the opposite surface, and the results averaged.

Results

The data obtained from AR-1 gages (3 gage elements, 45 deg apart) were employed to determine the orientation of the principal stresses. In all cases, the principal stresses in the surface plane were found to be approximately parallel to and perpendicular to the direction of welding. The maximum deviation observed was of the order of ±5 deg from this condition, and it is believed that errors in positioning of the gages exactly with respect to the weld were the primary cause of the observed deviations.

Figures 3–10 summarize, in graphical form, the averaged results of the residual stress measurements. In each of these figures, the usual sign convention has been followed (tensile stresses—positive sign, compressive stresses—negative sign). In each figure, the measured residual stress has been plotted as a function of location along the weld. For convenience in plotting, all locations are referred to the midpoint of the longitudinal axis of the weld (Fig. 1). In all cases, the direction of welding was from the extreme "minus distance" to the extreme "plus distance." Thus, the effect of plate dimensions and other variables on the residual stress level at corresponding locations in plates of several different sizes may be seen directly from the plots.

Discussion of Results

Effect of Plate Dimensions on Longitudinal Weld Stresses

Weld Length. Figures 3 and 4 summarize the effect of weld length on the residual longitudinal weld stresses in 20-in. wide specimens of commercially pure titanium and 7%-Mn titanium alloy, respectively. In general, it will be noted that the longitudinal weld stresses rise from zero at the edge of the plate to 18,000 to 29,000 psi in tension in the central portion of the commercially pure titanium. The maximum observed longitudinal stress ranges from 28,000 to 29,000 psi in the commercially pure titanium plates for weld lengths of 24, 20 and 16 in., falls to about 20,000 psi for the 14-in. weld length and averaged about 25,000 psi for the 10-in. weld length. Thus it appears that the critical weld length for unalloyed titanium is approximately 16 in., since all weld lengths measuring 16 in. or more resulted in approximately the same longitudinal stress level, while shorter weld lengths gave somewhat lower longitudinal weld stresses.

The maximum observed longitudinal weld stresses in the 7%-Mn titanium alloy ranged from 44,000 to 49,000 psi for weld lengths of 24, 20 and 16 in. From the shape of the stress-distribution curves, it would appear that a 16-in. weld length is very close to the critical weld length for the alloyed titanium; however, no additional specimens were available for investigating the effect of shorter weld lengths in this material.

Plate Width. Figures 5 and 6 summarize the effect of weld width on the longitudinal residual stresses for 16-in. long welds in commercially pure titanium and 7%-Mn titanium alloy. In all cases, the weld length was held constant at 16 in. It may be seen by inspection that the maximum observed

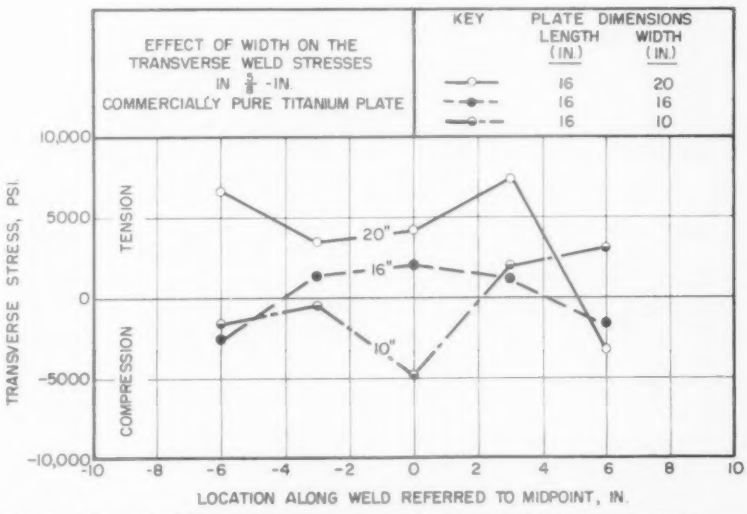

Fig. 7 Effect of width on the transverse weld stresses in 5/8-in. commercially pure titanium plate

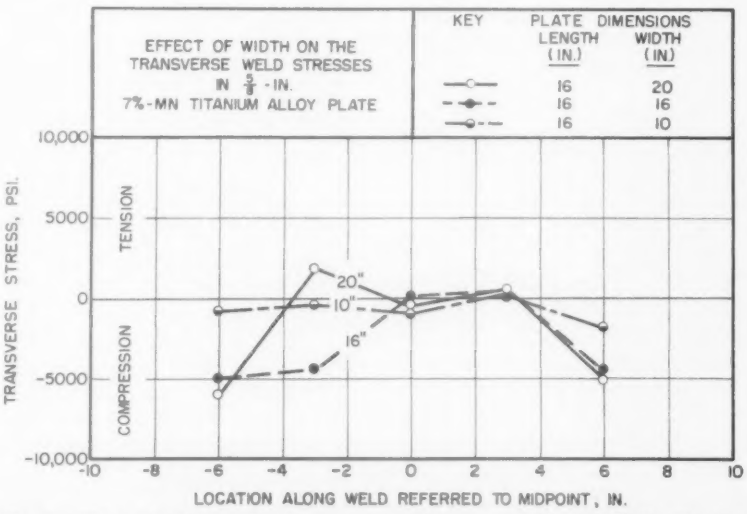

Fig. 8 Effect of width on the transverse weld stresses in 5/8-in. 7%-Mn titanium-alloy plate

residual stress decreased slightly as the width of the plates was decreased in both materials. For example, the maximum longitudinal stress diminished from 29,000 psi for 20-in. wide specimens (two 10-in. wide plates welded together) to 26,500 for 16-in. wide specimens, and was further reduced to 24,000 psi by employing a 10-in. specimen width. Reference to Fig. 6 reveals the same trend for the 16-in. weld length in alloyed titanium, where the longitudinal stress dropped from 45,000 psi for the 20-in. width, to 39,500 psi for the 16-in. width, to 36,500 for the 10-in. width.

Figures 7 and 8 summarize the effect of plate width on the transverse weld stresses in commercially pure titanium plate and 7%-Mn titanium plate, respectively. In all cases, the weld length was held constant at 16 in. Inspection of Fig. 7 reveals that the plate width appears to have a significant effect on the transverse weld stresses in commercially pure titanium plate. Transverse tensile stresses of up to 7500 psi were observed in the 20-in. wide plates, whereas the maximum transverse tensile stresses were significantly lower with both the 16-in. wide and 10-in. wide plates. With the narrower plates, a larger proportion of the weld exhibited compressive stresses, as may also be seen from an inspection of Fig. 7.

The 7%-Mn titanium alloy exhibited transverse tensile stresses only of comparatively low magnitude. The maximum observed transverse tensile stress of about 2000 psi again was associated with the 20-in. wide plate. In general, transverse compressive stresses predominate over a larger length of the weld in the 7%-Mn alloy. It is believed that this apparently abnormal behavior can be explained as follows:

1. During heating, the close-packed hexagonal α phase transforms to the body-centered cubic β phase, resulting in expansion in the weld heat-affected zone.

2. The rate of cooling in portions of the weld heat-affected zone is sufficiently fast to cause transformation of the β phase to β' martensite, again accompanied by expansion.

3. Therefore, the heat-affected zones on either side of the weld undergo an expansion at a comparatively low temperature, thus leaving residual transverse compressive stresses along much of the weld length.

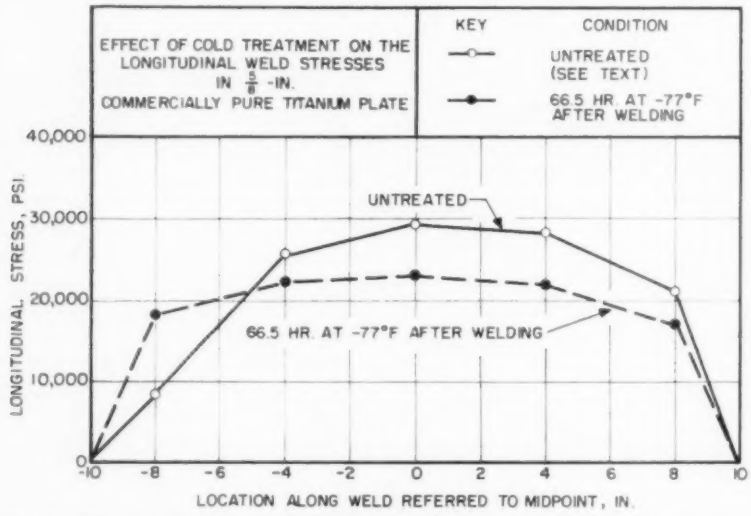

Fig. 9 Effect of cold treatment on the longitudinal weld stresses in $^5/_8$-in. commercially pure titanium plate

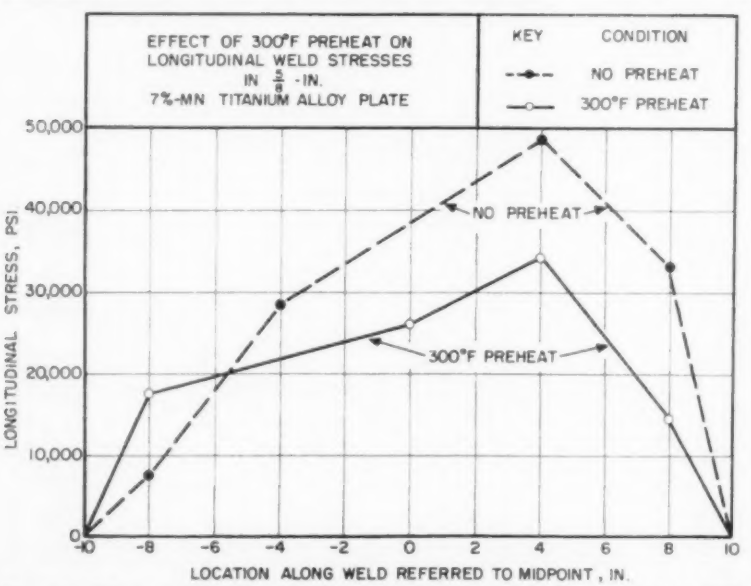

Fig. 10 Effect of 300° F preheat on longitudinal weld stresses in $^5/_8$-in. 7%-Mn titanium-alloy plate

Effect of Cold Treatment on the Longitudinal Residual Weld Stresses in Commercially Pure Titanium Plate

A commercially pure titanium plate 20-in. long x 16-in. wide was welded and then subjected to −77° F for 65.5 hr prior to making stress measurements. The results of the longitudinal stress measurements on this plate are summarized in Fig. 9. For comparison, the results of longitudinal stress measurements on a 20- x 20-in. plate in the as-welded condition have been included on the same plot. Unfortunately, the apparent reduction in longitudinal stress in the 20- x 16-in. plate cannot be attributed conclusively to the cold treatment, since no data are available for as-welded plate of the same dimension. In fact, as has been shown previously, reducing the plate width tends to produce a significant reduction in the longitudinal weld stresses (refer to Fig. 5). Therefore, it can only be stated that storage at sub-zero temperature did not have a pronounced effect on the residual longitudinal weld stresses.

Effect of 300° F Preheat on the Residual Longitudinal Weld Stresses in 7%-Mn Titanium-Alloy Plate

A 7%-Mn titanium-alloy plate 20 in. long x 16 in. wide was welded using 300° F preheat. The results of the longitudinal stress measurements on this plate are summarized in Fig. 10. One specimen cracked during sectioning, and the data obtained from this specimen are therefore included but are not used, since the gage readings were unreliable. In general, there appears to be a significantly lower level of residual stress at most points in the weld when a

300° F preheat is used. However, part of this apparent reduction is a result of the narrower plate (16 in.) used with the preheat study. The curve marked "no-preheat" was obtained from a 20-in. wide plate, and would be expected to show somewhat higher longitudinal stresses. However, it is believed that a portion of the observed reduction in stress can be attributed to the use of a 300° F preheat temperature, since the reduction in stress is nearly 25% for the preheated sample.

Observations on Weld Cracks

Experience at the Detroit Tank Arsenal has indicated that transverse weld cracks are common in plate longer than 8 ft. During the course of the present investigation, no transverse cracks were observed. However, numerous longitudinal cracks were observed in the 7%-Mn alloy material after sectioning to relieve the restraint of the surroundings. Upon standing, the incidence of cracking increased, suggesting that the mechanism might be related to the delayed cracking reported in the literature.[3] In general, the combination of high residual stresses and high-hydrogen content has been found to be a major cause of cracking in 8%-Mn titanium-alloy sheet. Therefore, in view of the high-hydrogen content of the welding wire employed in this investigation (see Table 3) and the residual stresses known to be present, it is not surprising that cracking should occur in the titanium weldments.

The fact that only longitudinal cracks were observed in the test coupons after subdivision is also understandable. In the as-welded condition, the longitudinal residual stresses are of higher magnitude, thus increasing the likelihood of the formation of transverse cracks in undisturbed weldments. However, when subdivided for stress measurement, the stress pattern is disturbed, and the transverse stresses, originally compressive in nature, may be transformed to tensile stresses by relaxation, while the longitudinal tensile stresses are largely relieved. Thus the subdivided coupons probably have the two factors required for delayed cracking, namely, residual stress and a high-hydrogen content in the weld metal. (It should be emphasized that complete relief of transverse stresses is not possible by subdivision, owing to the extremely steep stress gradient in the transverse direction.)

Conclusions

1. The residual longitudinal weld stresses in 5/8-in. commercially pure titanium plate range from 19,000 psi to 29,500 psi.
2. The residual longitudinal weld stresses in 5/8-in. 7%-Mn titanium alloy range from 36,000 psi to 49,000 psi.
3. Decreasing the length of the weld below 16 in. tends to decrease the magnitude of the residual longitudinal weld stresses in commercially pure titanium.
4. Decreasing the width of the specimens in the range 20 to 10 in. tends to decrease the residual longitudinal weld stresses in both the commercially pure titanium and in the 7%-Mn alloy.
5. Decreasing the width of the specimens in the range 20 to 10 in. tends to reduce the magnitude of the residual transverse tensile stresses in both the commercially pure titanium and the 7%-Mn titanium alloy.
6. Subjecting the welds in commercially pure titanium to −77° F for 65.5 hr appears to have little if any effect on the longitudinal residual stresses.
7. Welding the 7%-Mn titanium alloy with a 300° F preheat appears to produce a small reduction in the longitudinal residual stresses.

Acknowledgment

This work was supported by the Ordnance Department, U. S. Army, through the Detroit Arsenal, Centerline, Mich., under Contract DA-20-089-ORD-36696. The authors wish to acknowledge the experimental efforts of James K. Magor, Avigdor Gelbetz, Joachim Hauser and John P. Walsh.

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RESEARCH NEWS

Titanium Alloys

Principles and Application of Heat Treatment for Titanium Alloys. A. J. Griest and P. D. Frost, Titanium Metallurgical Laboratory, Battelle Memorial Institute. December 1957. 132 pages. (Order PB 121636 from OTS, U. S. Department of Commerce, Washington 25, D. C., $3.50.) The state of the art of titanium heat treatment is summarized as of Spring 1957. A section describes relationships between alloy constitution, microstructure and properties obtained on heat treatment. Another contains a collection of property data for selected commercial alloys in the heat-treated condition. Room-temperature and short-time-elevated temperature data are presented for all of the alloys. A third section discusses heat-treating practice, including furnace characteristics, coatings for minimizing contamination, and procedures for the control of distortion and flatness during heat treatment.

Standard Samples of High-Temperature Alloys

The National Bureau of Standards is conducting a program on high-temperature standard samples at the request of the Navy Bureau of Aeronautics and the Wright Air Development Center. Standards for both spectrometric and chemical analyses are being prepared to cover the composition ranges of 17 commercial types of high-temperature alloys. Research on new and improved methods of analysis is also under way, to ensure accurate analysis of the standards and optimum conditions for their application in other laboratories.

The Bureau now distributes over 550 standard samples of chemicals, metals and other materials to industrial and research laboratories for use in instrument calibration and process control. However, recent advances in jet aircraft, rockets and guided missiles have brought about a need for additional standard samples to aid in controlling the composition of alloys that can withstand the high temperatures encountered in these applications.

Such alloys are composed of heavy elements in a variety of compositions. The principal alloying elements are iron, nickel and cobalt in various proportions, to which may be added lesser amounts of carbon, manganese, silicon, chromium, molybdenum, tungsten, niobium, titanium and aluminum. In addition to the major alloying elements, the minor or trace elements present in the alloys, such as boron or zirconium, may have marked effects on their properties.

(*Continued on page 444-s*)

WELDING OF MOLYBDENUM-ALLOY SHEET

Authors describe the equipment and the arc-welding procedures used and present bend and tensile-test data for weldments in Mo–1/2% Ti sheet

BY K. M. KULJU AND W. H. KEARNS

INTRODUCTION. Molybdenum shows excellent promise as a structural material for use above 1800° F because of its high melting point, its strength at elevated temperature and its thermal conductivity. Oxidation protection and fabrication techniques are two fundamental problems that must be solved to produce molybdenum components. Special techniques are required for welding molybdenum, and significant new developments are necessary for successful molybdenum-alloy structures.

Molybdenum weldments are subject to porosity and loss of ductility at room temperature unless extreme care is exercised during welding. Poor room-temperature ductility has been found to be a function of oxygen and nitrogen in the welds. The oxygen and nitrogen content of the base metal must be small and the welding atmosphere controlled to prevent, to as great a degree as possible, contamination during welding.

Ductile welded joints were produced in pure molybdenum in 1951 in high vacuum. Subsequent alloy-development work produced the current molybdenum–1/2% titanium alloy sheet which has vastly superior weldability over unalloyed molybdenum. Welding studies at Battelle Memorial Institute showed that ductile welds could be produced in Mo–1/2% Ti alloy sheet using carefully controlled procedures.[1, 2]

A program was undertaken by the General Electric Flight Propulsion Laboratory Department to obtain mechanical properties of arc-welded joints in Mo–1/2% Ti sheet. A vacuum-purge inert-atmosphere welding chamber was constructed and successfully utilized in fusion welding of molybdenum sheet. This article describes the equipment and welding procedures used, and presents bend and tensile-test data for weldments in Mo–1/2% Ti sheet.

Summary

Tungsten-arc welds that exhibited room-temperature ductility were produced in commercial 0.062-in. Mo–1/2% Ti alloy sheet. The welds had an average room-temperature bend radius of 5 1/2T. Ductile welds had been produced in the alloy at other laboratories demonstrating that ductility is not associated with a single heat or welding procedure.

Tensile tests were made on welded specimens between 1600 and 2200° F. The welded joints had strengths comparable to those of recrystallized molybdenum but the strengths were significantly lower than wrought sheets. All specimens failed in the heat-affected zones. Nevertheless, the strengths were far superior to any cobalt or nickel-base alloy currently available. The 1800° F weld strength was 43,500 psi, decreasing to 23,000 psi at 2200° F.

K. M. Kulju and **W. H. Kearns** are engineers with the Flight Propulsion Laboratory Department, General Electric Co., Cincinnati, Ohio.

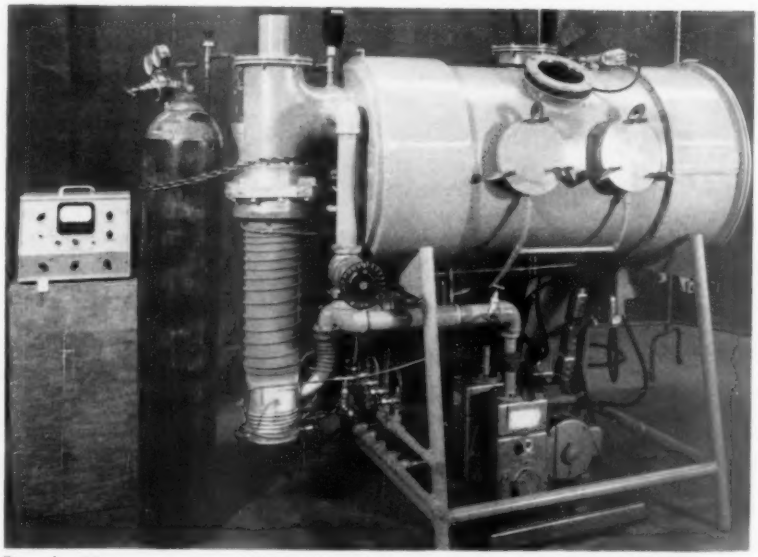


Fig. 1 Vacuum-purge welding chamber during pump down with glove-port covers in place

Material

A welding study was conducted on 0.062-in. thick arc-cast molybdenum–1/2% titanium alloy sheet obtained from a commercial vendor. Typical room-temperature mechanical properties of the sheet were as follows:

Tensile strength, psi	106,000
0.2% offset yield strength, psi	85,000
Elongation, %	15
DPH No.	280

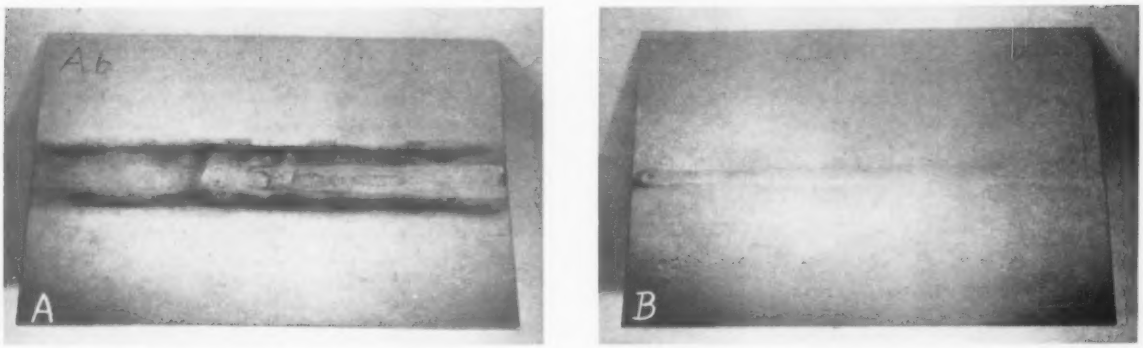
The chemistry of this material was as follows:

Chemical Analysis, Weight %	
C	0.021
Ti	0.43
O	0.0009
N	0.0007
H	0.0001

Oxygen, nitrogen and hydrogen contents were determined by vacuum-fusion analysis. The carbon analysis was determined using a combustion technique and the titanium content was analyzed colorometrically. The carbon and oxygen contents were about 4 times higher than amounts necessary for producing ductile as-cast molybdenum. The nitrogen and hydrogen levels are well within acceptable limits.

Equipment

Special equipment was built and weld-



A. Face of weld

B. Root of weld

Fig. 2 Typical welded panel of Mo – 1/2% Ti sheet. Approximately X 1/2

Table 1—Procedure for Cleaning Molybdenum Sheet Prior to Welding

1. Degrease parts for ten minutes in Trichlorethylene vapor degreaser.
2. Immerse in alkaline cleaner for 2–3 min. (Commercial cleaner).
3. Rinse in cold water.
4. Buff and vapor blast.
5. Immerse in alkaline cleaner (same as No. 2).
6. Rinse.
7. Electropolish with 8 to 12 amp current in a bath of 80% H_2SO_4 at 130° F.
8. Rinse in cold water.
9. Wrap each part in a clean paper towel.

ing procedures were utilized to minimize contamination of the metal during welding. The welding was done in a helium atmosphere inside a vacuum-purged chamber. The chamber body was 24 in. in diameter and 48 in. long. Welding was accomplished manually through glove ports located on each side of the chamber. Two view ports enabled the operator to see the material during welding. A hinged cover plate provided an entry into the chamber for placing and removing the work.

The system was evacuated using a 15 cfm mechanical pump and a 6-in. diffusion pump.

Figure 1 shows the exterior of the vacuum chamber with the glove-port covers in place.

Welding current was provided by a 300-amp d-c rectifier-type welding machine. A 300-amp water-cooled tungsten-arc torch was used for all welding. Gas was not circulated through the torch. All weld panels were preheated by two infrared lamps. The preheat temperature was measured with a surface pyrometer.

Specimen Preparation

The cleanliness of the surfaces to be joined is extremely important because the slightest oxide film will cause room-temperature brittleness in weldments. To assure cleanliness, it is necessary to etch the edges of the sheets to be joined.

Weld test panels were cut from the rolled sheet and thoroughly cleaned. The cleaning procedure shown in Table 1 gave excellent results. The edges to be welded were examined closely for sheet laminations because they are sources of contamination. Any laminations were removed by grinding and the panels recleaned.

Table 2—Bend-Test Results on Tungsten-Arc Welds in 0.062-In. 1/2% Ti-Molybdenum Alloy Sheet

Test temperature, ° F	*Punch radius, in.*	*Head speed, ipm*	*Elastic strain, in./in./sec*	*Radius of bend, in.*	*Bend angle, deg*	*Elongation,* %*
80	1/4	1/4	0.001	7/32	97	12.5
80	1/4	1/2	0.002	11/32	45	8.5
80	1/4	1/2	0.002	1/4	55	11
80	1/4	1	0.004	5/16	55	9
80	1/4	1	0.004	5/32	75	16.5
80	1/4	1	0.004	>3/8	40	<8
80	1/4	1	0.004	3/8	55	8
80	1/4	1	0.004	>3/8	20	<8
80	1/4	1	0.004	>3/8	30	<8
200	1/8	1	0.004	1/8	105	20
200	1/8	1	0.004	5/32	100	16.5
200	1/8	1	0.004	5/32	75	16.5
200	1/16	1	0.004	1/8	105	20
200	1/16	1	0.004	5/32	105	16.5
200	1/16	1	0.004	5/16	90	9
300	1/16	1	0.004	1/8	105	20
300	1/16	1	0.004	3/32	105	25
300	1/16	1	0.004	3/32	105	25

Specimen size: 0.062 x 1/4 x 1 1/2 in.
Bend jig: 1 1/4-in. span, 75 deg V-block.
* Approximate for outermost fiber.

Welding Procedure

The cleaned specimens were placed in the vacuum-purge welding chamber and the chamber was evacuated to 0.1 micron. Then the chamber was filled with Grade A helium circulated through a dry-ice coil to remove any water vapor (Bureau of Mines designation). A weld bead was made on titanium sheet for several minutes to getter oxygen and nitrogen in the helium. Welding of molybdenum was not begun until the titanium weld bead was free of discoloration. Two specimens were placed in the welding fixture and held in place by hold-down plates. No backing was used under the joint. There was a clearance of 1/2 in. on either side of the joint and under the joint. The panels were preheated to 200° F and fusion butt welded using about 125-amp current and 3/32-in. tungsten electrode. No filler metal was added. Complete penetration was obtained in all welds with no indentation of the weld surface. The weld was very bright and clean. Figure 2 shows a welded test panel. The dark deposit noted in Fig. 2A was condensed metal vapor believed to be titanium. It was readily removed after welding and did not appear to be detrimental to weld quality. After welding, all test panels were given a stress-relief anneal for 1 hr at 1800° F in vacuum. The panels were radiographed and the welds were free of cracks and porosity.

Mechanical Tests

The welded joints were evaluated by

(1) a single-point load bend test to determine the degree of ductility and (2) a tensile test to determine elevated-temperature strengths. Considerable data have been compiled on bend ductility of molybdenum weldments and tensile data for the base metal, but no tensile data, up to now, have been developed for butt welds in molybdenum-alloy sheet.

Bend Tests

A simple transverse-bend test was used for evaluating weld ductility. In this test, the weld ran transverse to the specimen length and was placed parallel to and directly under the radius punches. The span was $1^1/_2$ in. Specimens were $^1/_4$ in. wide. The weld face was ground smooth to eliminate any notch effect caused by the large as-cast grain boundaries and the bead ripples.

All welds were tested with the face of the weld in tension. The load was applied at the center of the specimen with head speeds of $^1/_4$, $^1/_2$ and 1 ipm. Specimens were bent at 80, 200 and 300° F until fracture occurred, or to the limit of the V-block (105 deg bend). The specimens and the bend-test fixture were heated in an oil bath. An immersion heater, controlled by a rheostat, was used to regulate the oil bath temperature. The temperature was measured with a stem thermometer. After testing, the radii of bend and bend angle of the welds were measured.

The as-received base metal had a minimum bend radius of 1T at room temperature. Bend test results on the welded joints are listed in Table 2.

Welds tested at room temperature had an average bend radius of $5^1/_2$T. The bend angles ranged from 20 deg to 97 deg. The welds had room-temperature ductility. Best bend ductility was obtained at slower deflection speeds because of the sensitivity of molybdenum to strain rate. Welds bent at 200° F had an average bend radius of $2^1/_2$ T, showing a significant improvement at higher temperature. Welds tested at 300° F had an average bend radius of 2T.

The tests showed that molybdenum weldments have ductility at room temperature and that ductility improves at higher temperatures. The welded joints are quite sensitive to strain rate as evidenced by the decrease in ductility when the head speed (rate of strain) was increased.

Tensile Tests

Elevated-temperature tensile tests were conducted on the welded joints in vacuum. The specimen design is shown in Fig. 3. All tests were run with a head speed of 0.01 ipm. The ultimate vacuum obtained during testing was in

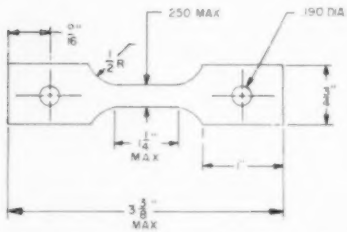


Fig. 3 High-temperature tension-test specimen

Table 3—Tensile Properties of Tungsten-Arc-Welded Joints in 0.062-In. $^1/_2$% Ti-Molybdenum Alloy Sheet

Test temperature, ° F	*Tensile strength, psi*	*0.2% yield strength, psi*	*Elongation in 1.3 in., %*
1600	43,500	34,900	7.6
1800	44,500	29,800	9.8
1800	45,000	31,400	10.7
1800	44,700	29,800	8.9
2000	39,800	29,000	8.5
2000	38,000	32,600	8.5
2000	38,500	26,100	9.0
2200	22,200	14,400	16.8
2200	23,400	17,600	16.2
2200	23,400	14,900	16.2

Heat treatment: 1800° F—1hr—vacuum.
Head speed: 0.01 ipm.
Test vacuum: 9-30 microns of mercury.

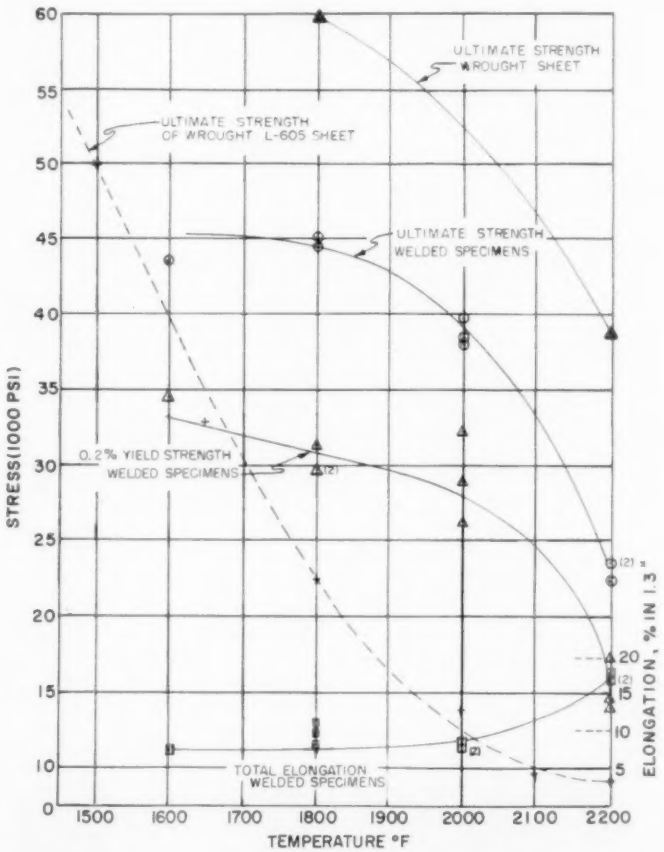


Fig. 4 Tensile properties of welded and unwelded 0.062-in. molybdenum—$^1/_2$% titanium-alloy sheet

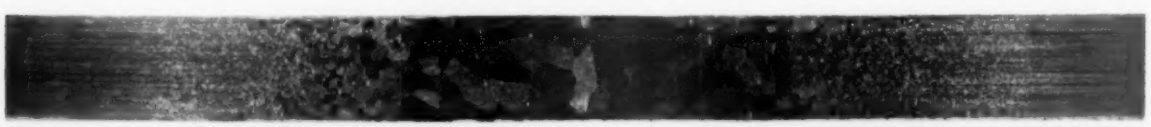


Fig. 5 Macrophotograph of a fusion weld in Mo—$^1/_2$% Ti alloy sheet showing the weld zone, heat-affected zone and extent of recrystallization of each side of the weld. X 10

A. Wrought base material

B. Extreme edge of heat-affected zone

C. Heat-affected zone

Fig. 6 Photomicrographs illustrating varying microstructure of a weld in Mo – $^1/_2$% Ti alloy sheet. X 250. (Reduced by $^1/_2$ upon reproduction)

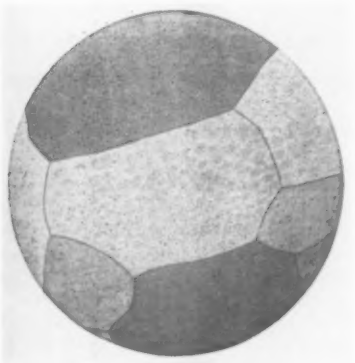


Fig. 7 Photomicrograph illustrating the structure of the weld zone in Mo – $^1/_2$% Ti sheet. This structure shows the large as-cast grains of the weld metal. Note the evidence of a substructure within the large grains. X 250. (Reduced by $^2/_3$ upon reproduction)

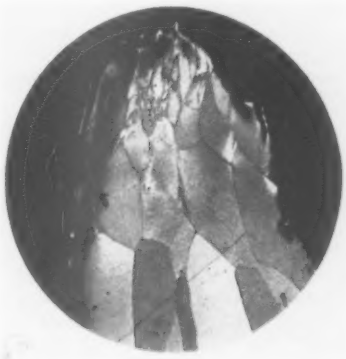


Fig. 8 Structure near fracture area in a welded Mo – $^1/_2$% Ti sheet tensile specimen tested at 1600° F. Note the large grains and elongation of grains in immediate area of fracture. X 100. (Reduced by $^2/_3$ upon reproduction)

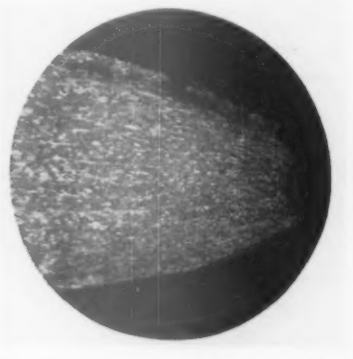


Fig. 9 Fracture area in a welded tensile specimen in Mo – $^1/_2$% Ti sheet tested at 2200° F. X 100. (Reduced by $^2/_3$ upon reproduction)

the range of 9 to 30 microns.

The tensile data for welded joints in Mo–$^1/_2$% Ti sheet are listed in Table 3. The tensile strengths are comparable to short-time stress-rupture data for recrystallized molybdenum. All specimens failed in the heat-affected zone after considerable reduction in area. Very low elongation occurred in the weld zone. The data are plotted graphically in Fig. 4. The ultimate strength of L-605 is plotted to illustrate the increased strength of Mo–$^1/_2$% Ti over a typical cobalt-base high-temperature sheet alloy. The welded-joint strengths of molybdenum were about $^1/_2$ to $^2/_3$ those of base sheet material.

Metallographic Examination

Weldments were examined metallographically to determine the microstructure of the weld and the effects of welding on the base material. Figure 5 is a photograph of a butt weld in Mo–$^1/_2$% Ti alloy. Molybdenum weldments have four separate zones of microstructure. These are (*a*) large as-cast grains of the weld metal, (*b*) equiaxed grains of the recrystallized heat-affected zone, (*c*) partially recrystallized, partially wrought zone and (*d*) wrought, unaffected base metal. These zones are shown in Figs. 5 and 6.

Figure 6A shows the microstructure of the base material; Figure 6B illustrates the microstructure of the partially recrystallized zone; Figure 6C shows the fully recrystallized heat-affected zone. Note the difference in grain size between Figs. 6B and 6C. The molybdenum weld metal exhibited a substructure within the large cast grains. The subgrains actually cross the larger grain boundaries. The composition of the dark precipitate within the grains in Fig. 7 is unknown.

Figure 8 is a photomicrograph of the fracture area in a 1600° F tensile-test specimen. Considerable elongation of the grains was noted and failure occurred in the large recrystallized grains in the heat-affected zone. Figure 9 is a photomicrograph of a weld tensile fracture in a 2200° F test specimen. Here the fracture occurred in the fine grains at the extreme edge of the heat-affected zone, showing that the fracture shifted with increasing testing temperature. The change in location of fracture at elevated temperature appears to be related to grain size. The larger grains appear to be stronger at high temperature than the smaller ones.

General Discussion

Several laboratories have produced ductile welds in different heats of molybdenum-alloy sheet with different equipment. This work and papers published recently have confirmed this.[2, 3] Recent advancements in the technology of welding molybdenum have made it possible to produce experimental welded-molybdenum components.

Molybdenum weldments possess useful strength at temperatures beyond the maximum useful temperatures for cobalt and nickel-base alloys. The molybdenum weldments exhibit good ductility at elevated temperatures. Further development is necessary, however, to improve the room-temperature ductility of welds in molybdenum components.

A welded joint is composed of the weld metal and the two heat-affected zones. Both types of structure must be ductile to obtain a ductile joint. The weld-metal ductility is influenced by base-metal and filler-metal compositions, welding atmosphere and welding technique. The heat-affected-zone ductility is influenced by base-metal composition and fabrication history. It is impossible to arc weld without producing a recrystallized heat-affected zone.

Therefore, the recrystallized base metal must be ductile to produce a ductile weld joint. Further development in melting, alloying and fabrication techniques is needed to accomplish this consistently in all wrought material used in welded structures.

Although the welding described here was done in a gastight enclosure, work at other laboratories has demonstrated that the welding can be done in the open, provided the shielding is carefully designed for each application to exclude air.

Conclusions

The following conclusions can be drawn concerning the state of the art of molybdenum welding:

1. Ductile welds can be produced in Mo – ½% Ti alloy sheet.
2. The weld joints have useful ductility and have tensile strengths at temperatures above 1800° F that are far in excess of presently available cobalt and nickel-base alloys.
3. The zones of weakness in welded joints at temperatures above 1800° F are the heat-affected zones.
4. The welded joints have sufficient ductility at 300° F to permit moderate forming.
5. Simple parts can be fabricated of molybdenum alloys by welding when done with carefully controlled procedures.

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RESEARCH NEWS

(*Continued from page 439-s*)

Control of composition of the individual alloys within narrow limits is important to their fabrication and successful end use. However, because of the complexity of the alloys, chemical analyses are difficult and time consuming. On the other hand, optical and X-ray spectrometric methods offer considerable promise for rapid analysis provided that suitable standard samples of known composition are available for calibration of the spectrometers. The spectrometric standards now being prepared should meet this need.

Both the Department of Defense and industrial groups have assisted in selecting the types of alloys needed for standards and the priority with which they should be prepared. As the result of meetings which the Bureau held with interested groups on June 15, 1956, and Nov. 19, 1957, a series of 23 spectrometric standards of high-temperature alloys was selected for issuance and production was begun. The alloys and nominal compositions to be covered by the proposed spectrometric standards are listed in Table 1. A chemical standard sample for Waspaloy is also being prepared in the form of chips. Its nominal composition is as follows: C, 0.07; Cr, 19.0; Ni, 58.0; Co, 14.0; Mo, 4.0; Ti, 3.0; Al, 1.25; Mn, 0.5; Si, 0.25; Zr, 0.07; and B, 0.004%.

Standards for six of the alloys of Table 1 (Nos. 1, 5, 6, 7, 12 and 17) have been prepared at the Bureau by remelting and casting commercial heats under argon. The six standards have been further processed at the Naval Gun Factory by forging into rectangular slabs, removing the center and end sections, and fabricating the remaining sections into rods. After homogeneity tests, the standards will be analyzed chemically and certified as NBS standard samples. A similar procedure will be followed for the remaining standards except that melting and fabrication will be done largely through commercial facilities.

In connection with these standards, methods of X-ray and optical spectrometric analysis are being investigated to provide for rapid tests of homogeneity and for determination of composition, especially for the minor and trace constituents. Also, improved chemical methods are being developed for the analysis of the various types of high-temperature alloys listed in Table 1.

Table 1—Spectrometric Standards of High-Temperature Alloys (In Preparation)

	Nominal chemical composition, %												
Name of alloy	*C*	*Mn*	*Si*	*Cr*	*Ni*	*Co*	*Mo*	*W*	*Nb*	*Ti*	*Al*	*Fe*	*Other*	*Number of standards proposed*
1. AISI 316*	0.10†	2.0†	1.0†	17	12	..	2.5	..	..	..	..	Bal.	..	1
2. A-286	0.05	1.35	0.50	15	26	..	1.25	..	..	2.0	..	Bal.	0.3 V	3
3. M-308	0.04	..	..	13	33	..	3.0	6.4	..	2.0	0.35	Bal.	0.20 Zr	1
4. Incoloy 901	0.05	0.5	0.35	13	40	..	6.0	..	..	2.5	0.20	Bal.	..	1
5. 16-25-6	0.08†	1.35	0.70	16	25	..	6.0	..	..	..	..	50	..	1
6. 19-9DL	0.30	1.10	0.60	19.0	9.0	..	1.25	1.2	0.40	0.30	..	66	..	1
7. N-155	0.15	1.5	0.5	21	20	20	3.0	2.5	1.0	..	..	Bal.	0.15 N	1
8. M-252	0.15	0.50	0.50	19	55	10.0	10.0	..	..	2.5	1.0	2.0	..	1
9. GMR-235	0.15	0.25†	0.60†	15.5	Bal.	..	5.25	..	..	2.0	3.0	10	0.06 B	1
10. Hastelloy W	0.12†	1.0†	1.0†	5.0	Bal.	2.5†	24.5	..	..	..	..	5.5	0.6 V†	1
11. Hastelloy X	0.15	..	..	22	45	..	9	..	..	..	..	Bal.	..	1
12. Inconel "X" 550	0.04	0.7	0.4	15	73	..	..	..	0.9	2.4	0.9	7	..	1
13. Inco 713	0.12	0.15	0.4	13	Bal.	..	4.5	..	2.25	0.6	6.0	1.0	..	3
14. Waspaloy	0.07	0.7	0.4	19	56	14	4.3	..	..	3.0	1.3	1	..	3
15. S-816	0.38	1.20	0.40	20	20	Bal.	4.0	4.0	4.0	..	..	4	..	1
16. L-605	0.15	1.50	0.50	20	10	Bal.	..	15	..	..	..	..	..	1
17. Nimonic 80A‡	0.1†	1.0†	1.0†	19.5	Bal.	2.0†	..	..	..	2.25	1.25	5.0†	..	1

* Stainless steel. † Maximum. ‡ British alloy.

CORRELATION OF METALLURGICAL PROPERTIES AND SERVICE PERFORMANCE OF STEEL PLATES FROM FRACTURED SHIPS

Relations between notch sensitivity, as measured by V-notch Charpy energy criteria, service performance, and chemical composition and grain size or plate thickness of the steel, were determined by statistical analyses of the accumulated data for 149 plates

BY MORGAN L. WILLIAMS

ABSTRACT. Structural failures involving extensive fractures in the hull plating of welded ships were investigated to determine causes of individual failures and to obtain data for evaluation of metallurgical and other factors that contributed to the origin and propagation of the fractures. Fracture initiation resulted from the coincidence of a notch or point of stress concentration and a plate that was abnormally notch sensitive at the operating temperature. Propagation or ending of a fracture was also related to the combined effects of stress and notch sensitivity of the steel. Relations between notch sensitivity, as measured by V-notch Charpy energy criteria, service performance, and chemical composition and grain size or plate thickness of the steel, were determined by statistical analyses of the accumulated data for 149 plates.

Introduction

During the winter of 1942–43, a number of welded merchant vessels and tankers experienced serious fractures. Some of these ships broke completely in two, and in others the strength deck or the bottom was completely fractured. The National Bureau of Standards was requested to assist in the investigation of these failures. Samples of the fractured plates were therefore submitted to the Metallurgy Division for examination. As welded ships continued to fracture, it became evident that the problem was a serious one, and the U. S. Coast Guard issued instructions to the effect that samples of the fractured plates, properly identified, should be sent to the National Bureau of Standards for study. This investigation has continued since that time* with two principal objectives: first, to determine the causes of the individual failures, and second, to obtain data for evaluation of metallurgical and other factors that contributed to the origin and propagation of the fractures.

This work has been directed primarily to examinations and laboratory tests of the fractured plates and correlation of the observations and test results with service experience. Inquiries into other phases of the ship fracture problem and related studies have been conducted by a large number of investigators in this country and abroad.[1]

Samples from 116 ship failures were received through the cooperation of the U. S. Coast Guard and other interested agencies. An appraisal of the relative number of samples examined and tested, compared to the total number of casualties reported in the years 1942–53, is presented in Table 1. Tests of plate material were completed on samples from 77 ships, of which 51 were Group I casualties.† Thus the samples tested represent nearly 20% of the 260 Group I casualties reported and a much smaller proportion of the less serious but more frequent Groups II and III casualties. As shown in Table 1, the sample ratio for Group I casualties is small for the Liberty ships (Type EC2) and the small C1 cargo ships, in which a large number of failures occurred in the early years, whereas laboratory tests were completed on one-third to one-half of the Group I casualties of the other major types of welded vessels built during the period 1940–53. These variations in sampling had the effect of emphasizing, in the analyses given below, plates from the serious casualties that occurred after the worst defects in design and workmanship of the earlier all-welded ships had been corrected.

For each ship failure from which plates were submitted, information was obtained regarding the location of the plates in the ship, the circumstances and extent of the casualty, and other pertinent details. From this information and from visual examination of the samples, the starting points of the fractures and some of the conditions that contributed to the failures were determined. On the basis of these preliminary studies, representative plates were selected for detailed examination and testing. This report summarizes the most important results from these examinations; more detailed information is available in the series of reports to the Ship Structure Committee,[2, 3] publications[4, 5, 6] that have been prepared during the investigation, and on a series of data cards (see Appendix A of Reference 3) that may be made available by the Ship Structure Committee.

Factors Involved in Structural Failures

The origins of the fractures could be

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The opinions expressed herein are those of the author and do not necessarily represent those of the Ship Structure Committee; the Bureau of Ships, Navy Department; or the National Bureau of Standards.

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† Casualties are classified as follows:
Group I—Serious casualties involving at least one fracture that has weakened the main hull structure so that the vessel is lost or is in a dangerous condition.
Group II—Casualties involving a fracture (usually less than 10 ft long) that does not endanger the ship but involves the main hull structure at a location which experience has indicated is a potential source of a dangerous failure.
Group III—Casualties of the hull structure that do not fall into Group I or Group II.
Other—Casualties not involving the hull structure, such as masts, rudder tubes or appendages not directly connected to the hull.

Table 1—Summary of Casualties Reported, Tests Completed to Dec. 31, 1954, Percent of Casualties Tested, and Samples not Tested, for Various Vessel Types

Vessel Type	WC2	T2	VC1	C1	C2	C3	Ch	Tkr	WT1	Riv	Other	Total
Casualties Reported to March 31, 1953 (a)												
Group 1	145	53	4	10	13(b)	7	2	11	5	1	9(c)	260
Groups 1 & 2(d)	839	216	20	56	79(b)	67	13	–	–	–	– (d)	1290
Tests Completed at NBS to December 31, 1954												
Group 1	12	17	2	0	5(b)	3	1	5	3	1	2(c)	51
Group 2	5	5	1	0	0	1	0	0	2	1	1	16
Subtotal	17	22	3	0	5	4	1	5	5	2	3	67
Group 3	3	1	0	0	0	0	0	0	0	1	1	6
Other	2	0	2	0	0	0	0	0	0	0	0	4
Total	22	23	5	0	5	4	1	5	5	3	4	77
Percent of Casualties Reported on which Tests are Completed (Sample ratio)												
Group 1	8	32	50	0	38	43	50	45	60	100	22	20
Group 1 & 2	2	10	15	0	6	6	8	–	–	–	–	–
Samples Not Suitable for Tests of Plate Material												
Group 1	1	–	–	–	–	–	–	–	–	–	–	1
Group 2	2	–	–	–	4(c)	–	–	–	–	–	–	6
Group 3	4	–	–	–	–	–	–	–	–	1	1	6
Total	7	–	–	–	4	–	–	–	–	1	1	13
Samples Not Tested to Date (e)												
Group 1	2	5	–	–	3	3	–	1	1	–	3	18
Group 2	–	–	1	1	5	1	–	–	–	–	–	8
Total	2	5	1	1	8	4	–	1	1	–	3	26
Total Samples Received												
All Groups	31	28	6	1	17	8	1	6	6	3	7	116

(a) Adapted from Board Report and SSC Technical Progress Reports 1, 2, and 3.

(b) Includes Navy operated C2 not listed in References (a)

(c) Includes casualties since date of Third Technical Progress Report.

(d) Certain types of vessels not included.

traced invariably to points of stress concentration such as hatch corners, ladder cutouts, ends of stiffeners or welding defects. Therefore, early in this investigation period, extensive structural alterations were made on existing ships and in new construction to reduce stress concentration. The incidence of failures was reduced materially by these improvements and by concurrent improvements in welding workmanship that reduced the number of local areas of high stress concentration.

However, it is obviously impossible to eliminate all stress concentrations. A number of failures originated at notches caused by defects that were introduced after the vessel was in service, such as resulted from minor accidents or poor welding practice during alterations. The properties of the steel thus had an important bearing on the failures.

No information was available regarding the stresses and stress concentrations that existed in the plates at the time of the fractures. In fact, when the early welded ships were built, very little was known about the magnitude of the stress concentrations that might occur in a ship under various operating conditions. The numerous factors contributing to the total stress at a given point were so complex and variable that even the average stress could not be estimated with any degree of accuracy. Conventional tension tests revealed nothing that might indicate the stress levels at which the failures occurred. Tensile properties of plates in which fractures started were apparently just as good as those of plates in which fractures ended or of plates that did not fracture. The tension tests and bend tests that were made on a few of the plates* indicated that the plates that fractured in service would meet the specification requirements under which they were purchased. Most of the failures occurred at temperatures below 50° F, suggesting that the temperature of transition from ductile to brittle behavior of some of the plates was in the range of the operating temperatures of the ships (generally between 20 and 90° F). This assumption was verified by Charpy V-notch tests of the plate material over a range of temperature, as described in detail below in the section of this report entitled "Relation between notch sensitivity and fracture category."

* Bend tests were not generally made on the fractured plates because most of the samples received were so badly corroded that a fair test could not be made on the required full-plate-thickness specimens.

Visual and Metallographic Examination of the Plates

The fractures generally were of a brittle type, approximately perpendicular to the plate surface. The reduction of thickness was very small, usually less than 2 or 3%. The paint and scale on the plate surface were not cracked, even very near to the fracture, an indication that there was little or no gross plastic deformation. Many of these brittle fractures showed narrow bands of shear fracture or shear lips adjacent to the plate surfaces, and these shear lips probably accounted for most of the thickness reduction. The larger values of thickness reduction (2 to 4%) and the heavier shear lips were generally associated with plates in which the fractures ended.

Metallographic examinations, using a number of different techniques to reveal evidences of deformation, showed that in the vicinity of the brittle fractures the zones of deformation paralled to the fracture were extremely narrow and were usually confined to the grains in which the fracture occurred. Numerous secondary cracks were found in areas adjacent to the main fractures, usually less than $\frac{1}{4}$ in. away, but occasionally as far as 1 in. These cracks were transcrystalline and straight and in the same direction within a single grain, but usually changed direction when extending into adjacent grains. A small amount of deformation was evident near the ends of some of these secondary cracks and between the secondary cracks and the main fracture. Deformation twins, or Neumann bands, were also observed in areas near the brittle fractures. Little effort was made to assess the magnitude of small-scale plastic deformation immediately adjacent to the brittle fractures. The major effort was directed toward determination of the nature of the deformation, the extent of the volume in which it occurred, and a search for any metallographic features that might be associated with brittle behavior of steel. The metallographic examinations revealed no features that might serve to predict a tendency to brittle fracture.

Only a small percentage of the fractures in the ships were of the ductile or shear type. These were usually associated with the free edge of a plate, rivet holes, openings, or corrugations that allowed the plate to deform laterally. In a number of instances, fractures that had propagated from the hull plating into longitudinal stiffeners or corrugated bulkheads changed from the brittle to the ductile mode. Frequently, the ductile fractures in these less-restrained members were halted a short distance from the hull plating, although the fractures in the more rigidly restrained shell plates continued to prop-

agate in the brittle mode. In the cases of ductile fracture, it was evident on visual examination that the deformation extended for some distance on each side and ahead of the fracture. In most cases where a fracture stopped, it had changed to the ductile mode in a region that was subjected to less lateral constraint than at the origin of the fracture. Thus it can be seen that the performance of a steel in the conventional flat-plate tensile test bears little relation to the initiation and propagation of a brittle service crack. In fact, every steel specimen from fractured ships exhibited more than 15% elongation in 8 in. in the conventional flat-plate tensile test.

Ends of brittle fractures examined after they were broken apart in the laboratory or sectioned showed a characteristic thumbnail shape, with the fracture farther advanced at the center of the plate than near the plate surfaces. Some of these fracture ends had a narrow band or crescent of shear fracture at the end of the thumbnail that joined the surface shear lips. This was usually accompanied by a dimple in the plate surface which indicated increased deformation near the end of the crack. In others, however, there was no visible evidence of shear fracture or increased deformation near the end of the brittle fracture.

Fractures in welds occurred only in areas where very obvious welding defects were present. Such fractures did not propagate extensively in the weld metal but turned into an adjoining plate or in some instances stopped when they reached a more sound area of the weld. It was also noted that, in a number of cases far out of proportion to the relative areas of welds and plate metal, the fractures stopped at or near welds that were approximately perpendicular to the path of fracture. These facts indicate that the sound weld metal may have been superior to the plate metal in resistance to fracture. It is also possible that a stress pattern exists near some welds that is unfavorable for continued crack propagation and may therefore result in the stopping of a crack.

Relation Between Notch Sensitivity and Fracture Category

To evaluate the notch sensitivity of the steels, Charpy V-notch impact tests were made over a range of temperatures.* After a few plates had been tested, it was observed that plates in which the fractures originated were more notch sensitive than plates that did not contain a fracture source. It appeared that some information might be gained by comparing the plates on this basis, in the absence of definite knowledge of the stresses and stress concentrations that existed in the plates at the time of the fracture. Therefore, after study of all of the data, the 178 plates that had been tested were classified in eight categories as follows.

S1—Plates containing the source of a primary or independent fracture which occurred under normal operating conditions.

S2—Plates in which secondary fractures started ahead of the main fracture, or plates in which fractures started under unusually severe loading conditions.

T1—Primary through plates that were the first to propagate a fracture, that is, where the fracture originated in an adjoining weld and turned or ran directly into the plate.

T2—Secondary through plates that propagated a running crack, that is, plates that fractured after the crack had propagated for some distance in another plate. (In all of the samples included in this category, the fracture had already propagated a foot or more before entering the plate under consideration.)

E1—Plates in which fractures ended but where there appeared to be structural features or stress conditions that may have influenced the ending of the fracture.†

E2—Fracture end plates where there was no apparent structural factor or stress condition involved in the stopping of the fracture.

NF—(No Fracture). Plates that did not contain a fracture but were adjacent to a fractured plate.

X—(Excluded Plates.) Miscellaneous plates to be excluded from the following analyses because of: (a) uncertainty as to proper fracture category or location and orientation of the plate in the ship, (b) insufficient or nonstandard V-notch Charpy test data, or (c) unusually severe deformation of the plate.

A total of 141 plates in the six fracture categories and 8 "no fracture" plates were used in the following analyses.

The results of the Charpy tests are summarized in Table 2 in terms of the average transition temperatures at the 10, 15 and 25 ft-lb levels for the plates in each fracture category. It can be seen that, regardless of the criterion used, there is a significant difference between the source plates and those that did not contain a source.

Table 3 summarizes the Charpy V-notch test results in terms of energy absorbed at a testing temperature equal to the failure temperature of each plate. The number of plates in each category is less than in Table 2 because in several

*Most of the Charpy specimens were cut with the long axis of the specimen parallel to the rolling direction and with the notch perpendicular to the plate surface. All of the data discussed in this report are from such specimens. Results from some specimens prepared with other orientations are given on the data cards mentioned above.

†Examples are: a fracture ending at a structural reinforcement; a fracture entering the low-stress area in the deck between hatch openings; or a fracture approaching a neutral axis of the vessel. A neutral axis, or area where the stress changes from tension to compression, may result from buoyancy conditions or from the effects of intact structural members, that is, if the entire ship is considered as a beam subjected to a bending moment.

Table 2—Summary of Transition-Temperature Data for Different Fracture Categories

Fracture category	*Number of plates*	*Thickness of plates, in. avg.*	*Observed V-notch Charpy transition temperatures, ° F* — T_{V10} *Avg.*	T_{V10} σ	T_{V15} *Avg.*	T_{V15} σ	T_{V25} *Avg.*	T_{V25} σ
S1	21	0.82	78	23	101	27	128	31
S2	26	0.74	58	15	81	15	110	20
T1	24	0.80	50	23	69	24	94	27
T2	28	0.74	47	14	65	14	89	14
E1	21	0.74	51	13	71	12	94	16
E2	21	0.64	22	17	39	18	61	21
All	141	0.75	51	23	71	26	96	29

Table 3—Summary of Data Related to Failure Temperatures of the Plates

Fracture category	*Number of plates*	*Thickness of plates, in. avg.*	*Temperature at failure, ° F avg.*	*V-Notch Charpy energy at failure temperature, ft-lb* — *Avg.*	σ
S1	19	0.83	49	7.1	2.1
S2	20	0.77	44	8.1	2.3
S1 + S2 = S	39	0.80	46	7.6	2.2
T1	20	0.81	41	9.4	4.1
T2	27	0.73	38	9.3	3.1
E1	16	0.75	45	9.2	1.9
T + E1 = T*	63	0.76	41	9.3	3.2
E2 = E*	18	0.66	50	19.1	10.1

instances the temperature at the time failure actually occurred is not known. In this table the data are also presented in three category groups: S = source, T* = through plus E1, and E* = E2. It was considered that the E1 plates should be classified with the "through" group because the data of Tables 2 and 3 show that these plates were significantly different from the E2 plates, whereas they were very similar to the through plates. These data indicate that the E1 plates might have been fractured through except for factors that reduced the stress. (See preceding footnote and definitions of E1 and E2 categories above.)

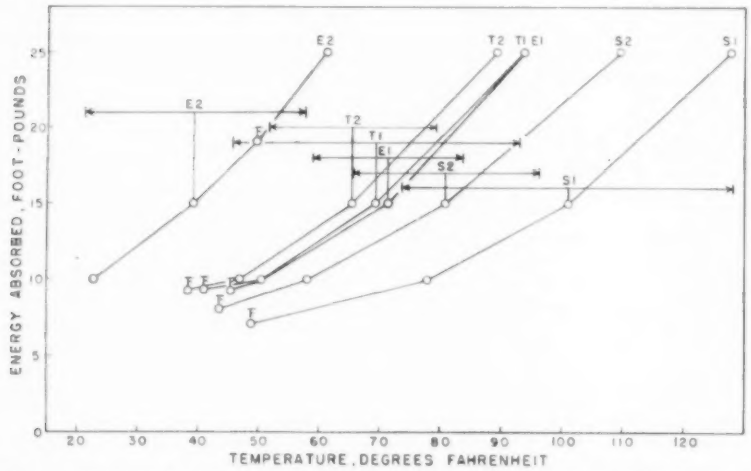

Fig. 1 Average V-notch Charpy transition curves for plates in the different categories. "F" indicates average failure temperature. Arrows indicate standard deviation ($\pm 1\ \sigma$) at the 15 ft-lb level

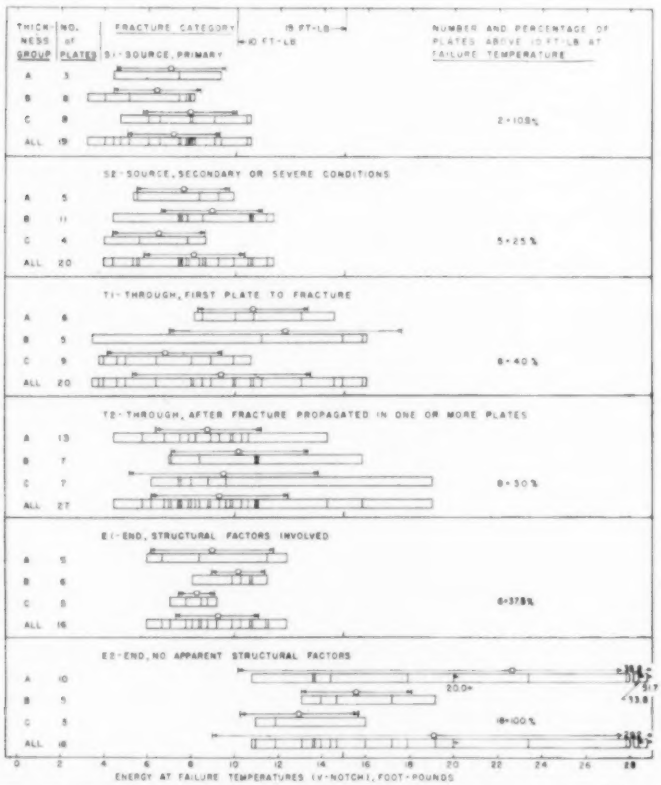
THICKNESS GROUP
NO. OF PLATES
FRACTURE CATEGORY
15 FT-LB
10 FT-LB
NUMBER AND PERCENTAGE OF PLATES ABOVE 10 FT-LB AT FAILURE TEMPERATURE
S1 - SOURCE, PRIMARY
S2 - SOURCE, SECONDARY OR SEVERE CONDITIONS
T1 - THROUGH, FIRST PLATE TO FRACTURE
T2 - THROUGH, AFTER FRACTURE PROPAGATED IN ONE OR MORE PLATES
E1 - END, STRUCTURAL FACTORS INVOLVED
E2 - END, NO APPARENT STRUCTURAL FACTORS
ENERGY AT FAILURE TEMPERATURES (V-NOTCH), FOOT-POUNDS

Fig. 2 Energy absorbed by V-notch Charpy specimens at the failure temperature of the plates. Circles indicate the average, and arrows show standard deviation ($\pm 1\ \sigma$) for each group. Horizontal bars indicate the range of values, and the vertical lines in each bar represent the values for individual plates

The average Charpy V-notch transition curves for the six fracture categories are plotted in Fig. 1 by taking the average transition temperatures at the 10, 15 and 25-ft-lb levels (Table 2) and the average energy absorption at the average failure temperature (Table 3) for each category.

It will be noted that the relations between the different categories are approximately the same at energy levels from below 10 ft-lb to more than 25 ft-lb and that at all temperature levels in the operating range of the ships the different categories are in the same relative order.

In order to provide comparisons between similar materials, the plates were divided into three thickness groups chosen so as to give approximately equal numbers of plates in each group as follows: A—Plate thickness less than 0.70 in.; B—Plate thickness 0.70 to 0.80 in., inclusive; and C—Plate thickness more than 0.80 in.

Figure 2 shows the energy at failure temperature for each plate in the different groups and fracture categories. Also at the right of the figure is shown the proportion of the plates in each category having energies greater than 10 ft-lb at the failure temperature.

Data on the 15 ft-lb transition temperatures of the plates are presented in more detailed form in Fig. 3, where the number of plates having transition temperatures in each 10° interval is shown for each of the fracture-category groups. Again, the through category includes E1 plates. The average and standard deviation are indicated for each group, and for the through plates a normal probability curve was drawn that has the same parameters as the experimental data. The dash-dot lines in the other parts of the figure represent the relative proportions of fracture-source plates to through plates, or end to through plates, in each interval of transition temperature. The widths of different portions of the bars indicate the different plate thickness groups and show that the heavier plates have generally higher transition temperatures than the thinner plates.

There is particular interest attached to a comparison of source and end plates from the same ship, as such a comparison would eliminate some of the factors that tend to cause scatter and overlap of the properties of the plates in the different categories. Figure 4 shows such data for the ten ships from which both a source and an end plate were tested and where the com-

Table 4—Summary of Average Grain-Size Numbers and Chemical Compositions for the Plates in the Different Fracture Categories

Fracture category	*No. of plates*	*Grain size no.*		*Average chemical compositions, %*							
		Fracture	*Ferrite*	*C*	*Mn*	*P*	*S*	*Si*	*Cu*	*Ni*	*Cr*
S1	21	3.9	7.0	0.28	0.42	0.019	0.034	0.030	0.05	0.03	0.02
S2	26	4.1	7.0	0.25	0.46	0.019	0.029	0.028	0.07	0.05	0.04
S1 + S2 = S	47	4.0	7.0	0.26	0.44	0.019	0.031	0.029	0.06	0.04	0.03
T1	24	4.4	6.8	0.24	0.44	0.013	0.031	0.049	0.05	0.04	0.03
T2	28	4.7	7.1	0.24	0.44	0.013	0.033	0.037	0.06	0.04	0.04
E1	21	4.1	6.9	0.23	0.45	0.012	0.030	0.038	0.06	0.04	0.03
T + E1 = T*	73	4.4	6.9	0.24	0.44	0.013	0.031	0.041	0.06	0.04	0.03
E2 = E*	21	5.3	7.2	0.21	0.45	0.011	0.031	0.044	0.08	0.04	0.03
No fracture	8	4.6	6.7	0.22	0.43	0.013	0.035	0.063	0.07	0.06	0.04
All plates	149	4.4	7.0	0.24	0.44	0.014	0.031	0.039	0.06	0.04	0.03

parison appeared to be valid. The fracture categories are arranged arbitrarily on the y-axis in such a way that the average values for all plates of each category lie on the heavy lines. The pairs of source and end plates are connected by lighter solid or dashed lines, and it can be seen that these lines do not cross as frequently as would be expected if the relation between source and end plates were a random one. This indicates a relation between the levels of notch sensitivity at which a fracture will start or end and some condition peculiar to the ship or the circumstances of the fracture. It can probably be inferred that this condition remains approximately constant during the brief time of propagation of the fracture. A fracture may start in a plate of very high notch sensitivity when this condition is relatively mild; and consequently, a relatively small degree of notch toughness would be sufficient to stop the fracture. However, if the potential source plate is less notch sensitive, a more severe condition such as a higher stress level or rate of stress application or a larger amount of stored elastic energy would be required to initiate fracture. In this case, because very little energy is required for brittle-fracture propagation, a higher degree of notch toughness or resistance to brittle fracture would be required to stop the fracture unless it propagated into an area of lower stress, as was the case for E1 plates.

Relation of Composition and Grain Size to Notch Sensitivity and Fracture Category

Table 4 lists the average chemical compositions of the steels in the different fracture categories, together with those for eight plates that did not contain a fracture. The table includes only those elements that were present in appreciable quantities and for which analyses were available on all plates. Small quantities of a few other elements were detected in several of the plates, and vacuum-fusion analyses for oxygen, hydrogen and nitrogen are available on about a third of the samples. This information is listed on the data cards mentioned above.

Table 4 also includes the average fracture grain size and the average ASTM ferrite grain-size numbers for the plates in each category. The fracture grain size of each plate was obtained by comparing the fractures of several brittle V-notch specimens (broken at low temperatures) with the fractures of a group of six specimens selected to give a gradation in apparent fracture grain sizes. These arbitrary "fracture standards" were assigned fracture grain-size numbers from 2 to 7, inclusive, determined by comparing the estimated prior *austenitic* grain size (from photomicrographs of the as-rolled steel containing ferrite and pearlite) with standard ASTM grain-size charts.

Ferrite-grain-size numbers were determined by taking the average of independent comparisons with standard ASTM grain-size charts by two observers. They examined a polished and etched section transverse to the rolling direction of each plate (or parallel to the fracture of the standard longi-

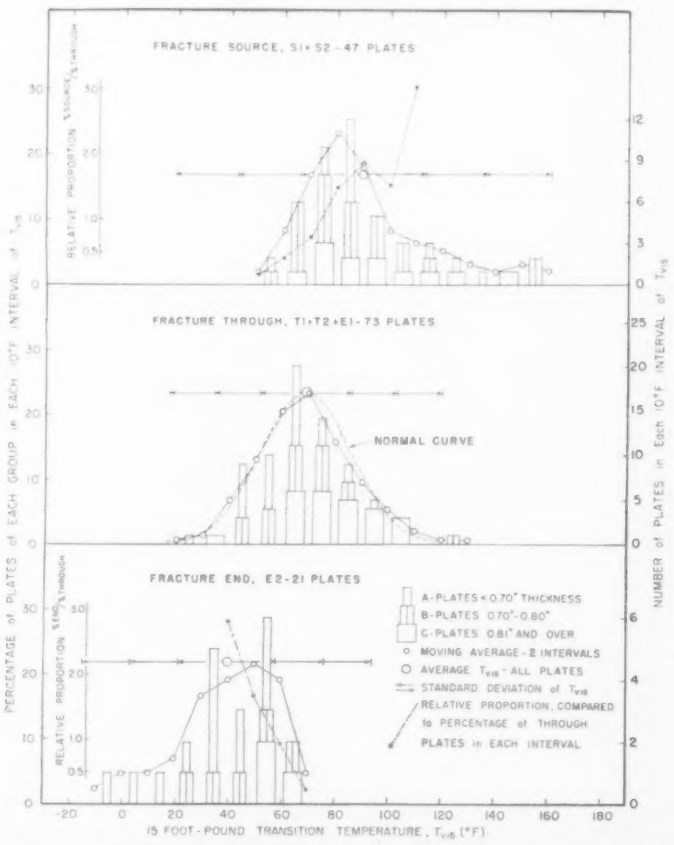
FRACTURE SOURCE, S1+S2 - 47 PLATES
FRACTURE THROUGH, T1+T2+E1 - 73 PLATES
NORMAL CURVE
FRACTURE END, E2-21 PLATES
A-PLATES < 0.70" THICKNESS
B-PLATES 0.70"-0.80"
C-PLATES 0.81" AND OVER
MOVING AVERAGE - 2 INTERVALS
AVERAGE T_{V15} - ALL PLATES
STANDARD DEVIATION of T_{V15}
RELATIVE PROPORTION, COMPARED to PERCENTAGE of THROUGH PLATES in EACH INTERVAL
PERCENTAGE of PLATES of EACH GROUP in EACH 10°F INTERVAL of T_{V15}
NUMBER of PLATES in Each 10°F INTERVAL of T_{V15}
15 FOOT-POUND TRANSITION TEMPERATURE, T_{V15} (°F)

Fig. 3 Frequency distributions of T_{V15} for revised grouping of the plates. Plates of the E1 sub-category are placed with the "Fracture Through" group

tudinal V-notch Charpy specimen). These determinations were facilitated by the use of a grain-size comparator developed by the Applied Research Laboratory of the United States Steel Corp. and kindly loaned for this purpose.

By plotting for each element, a graph or scatter diagram of the content of that element against the observed 15 ft-lb transition temperature for each plate, it was determined that T_{V15} increased with increasing amounts of carbon or phosphorus and decreased with increasing silicon content within the range of compositions of the plates. Corrections estimated from the slope of the scatter diagrams were made for the effects of these three elements on the transition temperature. The effects of some other elements (which had been obscured by the larger effects of the variations of C, P and Si) were revealed when the charts for each element were replotted using the "corrected" transition temperature for each plate. A similar plot showed a relation between the fracture grain size and the transition temperature, and provided a suitable correction factor. The corrections and replotting were repeated, with successive refinements of the correction factors for the different elements, until it became evident that some of the elements, when considered individually and in the amounts present in the plates under consideration, had relatively little effect on the transition temperature.

With the results of plotting as a guide and using the data for 118 plates, statistical methods revealed the effects of the four most important elements (C, Mn, P, Si) and the fracture grain size on the 15 ft-lb transition temperature.[6] Because the fracture grain size had been determined by a nonstandard method and because it appeared that other elements present in the steels might affect the transition temperature appreciably, the relationship between T_{V10}, T_{V15} and T_{V25} and the seven chemical elements plus an eighth "grain size or plate-thickness factor" were redetermined with additional data from 149 plates. Separate computations were made with the eighth factor as (a) the ferrite-grain-size number, (b) the plate thickness, or (c) the fracture grain-size number. The results of these analyses are summarized for T_{V15} in Table 5.* The numbers represent the coefficients by which the percentage of each element must be multiplied to find the change in transition temperature (in degrees Fahrenheit) due to that element. It can be seen that the coefficients for the major elements C, Mn, P and Si are nearly the same for all three methods of computation. This indicates an approximate equivalence of the effects of ferrite or fracture grain size (Columns A and C, Table 5) or of plate thickness (Column B). Thus it appears that the generally higher transition temperatures of the thicker plates (Fig. 3) are more closely related to differences of grain size resulting from the finishing temperatures and cooling rates than to differences of chemical composition. However, it should be noted that this relation is valid only for steels of reasonably similar composition and manufactured under mill conditions and practices in use at the time these steels were produced.

In order to obtain an index that could be used to classify plates by source, through, or end category without reference to transition temperature, the discriminant function technique[3, 7] was used. This provides, in effect, an index that consists of a simple weighted average of the composition and grain size (or plate thickness). The weighting coefficients were determined from the known compositions of the plates in the different fracture categories so that the index or discriminant function would achieve optimum effectiveness in classifying a plate into one or the other

Table 5—Coefficients for Calculation of T_{V15}

	A	*B*	*C*
Constant	120	14	81
C	380	304	314
Mn	−68	−68	−87
P	314	332	308
Si	−297	−278	−271
Cu	−4	−49	1
Ni	−7	5	−56
Cr	−160	−120	10
Ferrite grain size no.	−14		
Plate thickness, in.		34	
Fracture grain size no.			−9

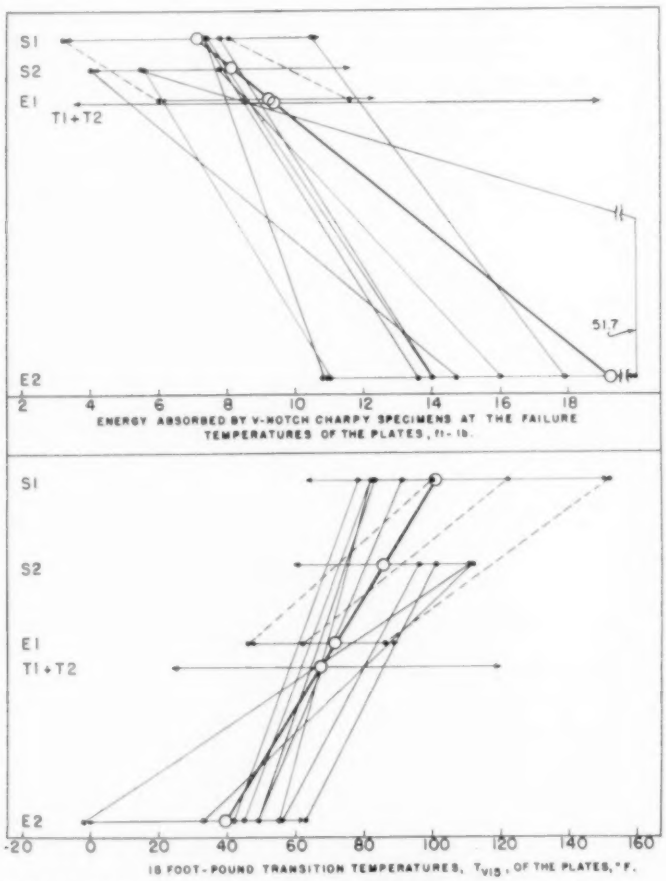

Fig. 4 Notch sensitivity of source and end plates from same ship, compared to ranges and average values for the different fracture categories. The fracture categories are spaced vertically so that the average values (large circles) fall on the heavy line. Other diagonal lines indicate relative values for pairs of source (S1 or S2) and end (E1 or E2) plates from the same ship. Horizontal arrows show the range of values for all plates in each category

* Similar relations for T_{V10} and T_{V25} are given in Table 13 of Reference 3.

of two groups. Table 6 gives the coefficients for the functions to discriminate between source and non-source or end and non-end plates. These computations were made using seven chemical elements plus either ferrite grain size or plate thickness as the eighth parameter.*

It will be noted that, with few exceptions, the coefficients in the discriminant functions are of the same sign as the corresponding coefficients in the equations for the transition temperature (Table 5). This shows that the effects of the different factors in promoting the initiation or termination of a fracture are, in general, similar to the effects of these factors in raising or lowering the V-notch transition temperatures.

It may be observed, however, that the coefficients of certain factors (particularly manganese, phosphorus and grain size or plate thickness) are of different relative magnitudes for the transition temperature and the two discriminant functions. This indicates a difference in degree between the effects of these factors on the V-notch properties and on the tendency to fracture in service. For example, manganese in the range of approximately 0.30–0.60% has an effect on the transition temperature (T_{V15}) about one-fifth as large as, but in the opposite direction to, the effect of carbon (Table 5). However, the effect of manganese in the end vs. non-end discriminant function (Table 6) is only about one-fourteenth that of carbon. Furthermore, manganese exerts a negligible influence on the probability of a plate falling in a source or non-source category; for the computation using ferrite grain-size number, the effect of manganese is still negligible but of opposite sign. This is contrary to the generally accepted belief, based on the results of V-notch and keyhole-notch Charpy tests and other tests of notched specimens, that increased manganese content or a higher Mn/C ratio increases the resistance to brittle fracture. This observation is of importance, not only in connection with the selection of steel for use in ships, but also as an indication that the notched-bar impact test is not a completely adequate criterion of the behavior to be expected from ship plate steel under service conditions.

It is customary, when the results of an investigation lead to a conclusion that is contrary to generally accepted views, to say that the conclusion should be verified by further work. This is probably not feasible in the present case because all the data (fracture category, chemical composition and grain size or plate thickness) for all plates that were definitely classified in the different fracture categories were used to determine the coefficients for the discriminant functions. Even if additional data were obtained for other similar steels of known fracture history, it is unlikely that the conclusion would be changed significantly because of the large number of plates that have already been used in the computation. This conclusion must therefore be checked on the basis of other available evidence.

The following observations and conclusions can be stated:

The discriminant functions establish separate criteria for the initiation (source vs. non-source) or the propagation or ending of a fracture (end vs. non-end). The Charpy V-notch test does not distinguish between initiation and propagation of fracture but measures the sum of several energy components, each of which may vary independently with the composition of the steel and with the testing temperature. The "transition temperature" is an artifice for selecting the temperature at which the sum of these independently varying energy components is a constant. However, this sum may include various proportions of the "initiation" and "propagation" energy components for steels of different compositions.

The discriminant functions are based on the relation of composition and grain size (or plate thickness) to the initiation or ending of a fracture *under the conditions encountered in service*. Thus these functions take into account differences of such factors as notch geometry, rate of stress application, and triaxiality of stress under service conditions, whereas these factors are fixed arbitrarily under the standardized conditions of the V-notch test. The discriminant functions also give due weight to the indirect effects of composition in relation to fabrication operations, such as the effect of composition on strain-aging embrittlement, hardening in the vicinity of welds or flame cuts, and weld performance or susceptibility to weld cracking. On the other hand, the transition temperatures of the plates were determined, in so far as possible, with V-notch specimens taken from areas unaffected by welding or fabricating operations. For example, the majority of the fractures in the ships originated in areas where the properties of the plates might have been changed by welding, flame cutting, cold deformation or strain aging. Additional V-notch specimens taken near such areas usually indicated a transition temperature higher than for the unaffected plate material. A number of investigators using different types of specimens have observed that welded specimens generally have a much higher ductility transition temperature than the corresponding unwelded specimens. Furthermore, unwelded steels that have identical transition temperatures may have widely different transition temperatures when welded.[9, 10] This difference is probably related to the effects of differences in chemical composition.

Table 6—Coefficients for Discriminant Functions

	*Source vs. non-source**		*End vs. non-end*†	
	A	*B*	*A*	*B*
Constant	−0.32	−0.69	0.40	−0.72
C	3.76	3.46	2.97	2.17
Mn	0.02	−0.004	−0.21	−0.17
P	12.2	12.7	2.3	2.2
Si	−4.77	−4.72	−1.50	−1.20
Cu	0.11	−0.06	−1.10	−1.56
Ni	1.3	1.4	1.0	1.2
Cr	−7.1	−7.0	0.4	0.6
Ferrite grain size no.	−0.06	...	−0.14	...
Plate thickness, in.		0.04		0.43

* Positive coefficients indicate factors that increase the probability that a plate will be in the source category.

† Positive coefficients indicate factors that increase the probability that a plate will be in the non-end category.

Effects of Carbon

Increased carbon content raises the V-notch transition temperature and also increases the probability of fracture initiation and propagation in service. The greater effect on fracture initiation than on propagation is probably related to the effect of carbon on weldability. Considering the range of carbon content in the ship-plate steels (0.13–0.37%) and the magnitude of the carbon coefficients, it is evident that carbon has a major effect on both the initiation and propagation of fractures in service, as well as on the V-notch transition temperature.

Effects of Manganese

Effects of manganese were discussed earlier in this section. The following

* The discriminant functions are in the form: $Y = b_0 + b_1 \times \%\ C + b_2 \times \%\ Mn + \ldots + b_8 \times$ Ferrite Grain-Size Number (or Plate Thickness) where b_0 = a constant and b_1 to b_8 are the coefficients for the various factors. The coefficients for the source-non-source discriminant function (Table 6) were determined so that if Y is plus (for a plate of given composition and grain size or thickness), the plate is more likely to be a source plate, but if Y is minus, it is more probable that the plate would be in a non-source category. For the end-non-end discriminate function, the reverse is true.

evidence confirms these observations:

1. The indication that manganese content has very little effect on the initiation of fracture was noted in earlier reports[2, 5] and is supported by the fact that the average manganese content for the larger number of plates tested to date is very nearly the same for the source (S1 + S2) through (T1 + T2 + E1) and end (E2) categories (Table 4). It is true that the average manganese content of the primary source (S1) plates is somewhat lower, but this is associated with higher average carbon content.

2. Previous computations of discriminant functions,[6] with a smaller number of plates and with the fracture categories grouped in a different way, also indicated that the effect of manganese on service fractures is much smaller than its effect on the V-notch transition temperature.

3. Results of the NRL drop-weight and explosion-bulge tests[8] indicate a good correlation with the results of this investigation for steels of similar composition, but for steels of higher manganese content the nil-ductility temperature appears to correlate with higher energy levels on the V-notch curve. This indicates that increased manganese content may not lower the nil-ductility temperature as much as it lowers the V-notch transition temperature. A direct correlation has not been made as yet to establish the effect of manganese on the drop-weight transition temperature.

4. The apparently better service performance of ships built in Europe during the period 1940–48 has been generally attributed to the higher Mn/C ratio of the European steels, since it was believed that carbon raised and manganese lowered the V-notch transition temperature. However, it is more probable that the lower casualty rate was due to the fact that the higher manganese permitted a lower carbon content for steels of the same tensile strength. In this respect, manganese (and some other elements that apparently have little effect when considered separately) may be beneficial in that they permit a reduction of carbon and hence of its deleterious effects.

Effects of Phosphorus

Phosphorus, although present in only small amounts in these steels, apparently has a pronounced effect on the initiation of fracture. In the source vs. non-source discriminant function (Table 6), the coefficients for phosphorus are about 3.5 times the corresponding carbon coefficients; whereas for the end vs. non-end discriminant function and for the transition-temperature relations (Table 5), the coefficients for carbon and phosphorus are nearly the same. This is probably related to the effects of phosphorus in regions affected by welding or oxygen-cutting operations. McGeady and Stout[10] reported that for welded plates the notch sensitivity showed a correlation with the phosphorus content considerably greater than for the same plates unwelded. It was noted in an earlier report on this investigation[2] that, in all of the plates with more than 0.04% phosphorus tested to that time, fractures had originated near a weld or flame cut.

Effects of Silicon

Silicon, in the amounts present in the steels examined in this investigation (0.00–0.12%), has an effect opposite to that of carbon. The coefficients in the discriminant functions indicate that an increase of silicon is about one-third more effective in reducing the probability of fracture origin than an equal *decrease* of carbon content and that the effect on the propagation or ending of a fracture is opposite to and about half that of carbon. In these steels, silicon lowers the V-notch transition temperature almost as much as carbon raises it. However, caution must be used in considering the effects of silicon. Other investigators[9, 11, 12] have shown that silicon in amounts greater than about 0.25% raises the transition temperature. Presumably, the effects on the initiation and propagation of fracture would be similar. A possible explanation of this reversal in the effect of silicon is that, in low concentrations, silicon acts as a deoxidizer and also combines with other elements present in the steel, while in higher concentrations the excess of silicon acts as an alloying element. The effectiveness of silicon in reducing the probability of fracture initiation may also be related to its effects in reducing the embrittling effects of aging.[9]

Effects of Plate Thickness and Grain Size

The coefficients for plate thickness in Tables 5 and 6 (Column B) show that a 0.1-in. increase of plate thickness is approximately equivalent in effect to an increase in carbon content of 0.01% for the transition-temperature relation, 0.02% for the end vs. non-end discriminant function, and only 0.001% for the source vs. non-source discriminant function. This indicates that plate thickness (like manganese) has a much smaller effect on the initiation of fracture than on the V-notch transition temperature. This conclusion is supported by the results of drop-weight tests which show that thickness *per se* has very little if any effect on the nil-ductility temperature (NDT). Heavy section tests conducted at the Naval Research Laboratory* have shown that sections up to 7 in. thick have essentially the same NDT (within ±10° F) as 1-in. slabs cut from the surface of the same material.

Similarly, the ferrite grain size has a smaller effect (relative to carbon) on the initiation of fracture than on the transition temperature. The coefficients (Tables 5 and 6, Column A) indicate that an increase of one grain size number (finer grain) is equivalent to a *decrease* of carbon content of 0.037, 0.047 and 0.016% for the transition-temperature relation, the end vs. non-end discriminant function, and the source vs. non-source discriminant function, respectively. In assessing these results, one should keep in mind the fact that the dispersion of grain-size measurements by the comparison method is relatively large compared to the observed range of values.

Effects of Minor Elements

The coefficients for copper, nickel and chromium in Tables 5 and 6 show some anomalies, especially in the case of nickel which appears here to deviate from its known effects on transition temperature and on brittle fracture. This is probably due to the fact that these elements were present in very small amounts in most of the steels and that the few steels in which they were found in appreciable (although still small) amounts did not provide a sufficiently large sample for this type of analysis. It should also be noted that other elements not included in the statistical analyses were present along with these elements, often in similar amounts.

Limitations of Analyses

The statistical analyses included neither hydrogen, nitrogen and oxygen, nor several other elements that the previous plotting method had indicated were of relatively minor importance in their effects on the transition temperature in these steels. Other possible relations that are not shown by these analyses are: (a) effects of different concentrations of the elements, for example 0.30–40% manganese vs. 0.50–60% manganese; (b) effects of one element in the presence of various concentrations of another element, such as the effect of manganese or silicon in 0.20 or 0.30% carbon steel; (c) effects of combinations of elements, such as silicon in the presence or absence of aluminum. Other investigators[11, 12] have shown that in many instances the transition temperature does not show a simple linear relation to the content of a particular element, and the same is probably true in the case of the discriminant functions. Therefore, one must be extremely cautious in interpreting these results or in attempting to extrapolate to steels of even slightly different composition.

A study is being made under another

* Private communication.

Ship Structure Committee project at the National Bureau of Standards to determine percent cleavage area of the fracture surfaces of the broken V-notch Charpy specimens from fractured ships. These data, which will include comparisons with the energy-criteria results of the present investigation, will be given in a future Ship Structure Committee report.

Summary

Examination of samples from more than 100 ships, tests of 178 plates selected from 77 of these ships and statistical analyses of laboratory test data and service experience for 149 of these plates have shown:

1. The fractures invariably originated at a mechanical or metallurgical notch resulting from design details, welding defects or accidental damage. The origin of the fractures at these points may be attributed primarily to stress concentration. In many cases the metallurgical effects of welding, oxygen cutting, or mechanical working were also present, but it is not possible from these data to separate out the effects of any single detrimental factor.

2. A number of the fractures originated in parts that are not ordinarily considered as structural strength members and then propagated through welds into the main hull structure. For instance, in one ship fractures started in defective butt welds of the bulwark cap rail at three separate locations. Each of these fractures propagated through the thin bulwark plate, through welds, and then into the side shell and deck of the ship. These failures show that, even for nonstrength members that are attached to a structure by welding, the standards of quality of materials, design and workmanship should be equal to those required in the main strength members of the structure.

3. The fractured plates met the requirements for chemical composition, tensile strength and ductility that were in effect at the time the ships were built.

4. The properties determined by tension tests showed no relation which was sufficiently marked to differentiate between the plates that did and the the plates that did not contain fracture sources.

5. Metallographic examinations did not reveal any features that could be associated with a tendency to brittle fracture.

6. The notch toughness properties of the plates, as measured by the V-notch Charpy test, showed a good correlation with the category (source, through or end) of the fractures that occurred in service. The average 15 ft-lb transition temperature (T_{V15}) of all source plates (S1 + S2) was 21° F higher, and that of the end plates (E2) was 29° F lower, than the average for the fracture-through plates. The lowest value of T_{V15} for a source plate was 59° F, and the highest value observed for an end plate was 63° F. Similar relations were observed for the 10 ft-lb and the 25 ft-lb V-notch transition temperatures, but the best all-around discrimination for steels of this type was found at the 15 ft-lb level. The energy absorbed by V-notch Charpy specimens at the failure temperatures of the respective plates averaged 7.6 ft-lb for the source plates, 9.3 ft-lb for the through plates, and 19.1 ft-lb for the end plates.

7. Subdivision of the source, through and end fracture categories indicated that: (a) primary fracture source plates (S1) were generally more notch sensitive than the S2 plates in which fractures originated under more severe stress conditions; (b) a through plate (T1) that was the first plate to propagate a fracture originating in an adjacent weld was not significantly different from a through plate (T2) that fractured after the crack had propagated a foot or more in another plate; (c) plates (E1) in which structural features or apparently low stress fields may have contributed to the ending of a fracture had considerably lower notch toughness than the remaining end (E2) plates and were not significantly different from the through plates.

8. In all cases in which source and end plates from the same ship fracture were available, the end plate had a lower transition temperature than the source plate. Comparison of corresponding pairs of source and end plates also indicates a relation between the levels of notch sensitivity at which a fracture will start or end and some condition peculiar to the ship or the circumstances of the fracture. This, together with conclusions 7(a) and (c) above, suggests that the initiation, propagation or termination of a crack is dependent to some extent on the stress level or some related factor as well as on the notch sensitivity of the steel.

9. Several factors appear to have important effects on the transition temperature or on the tendency to initiate or propagate fracture in hot-rolled steels of low-alloy content. Statistical analyses of the data showed that increases in carbon or phosphorus content increased the V-notch transition temperature and also increased the probability of fracture initiation in service. Increased silicon content (within the range 0–0.12% found in these steels) decreased both the transition temperature and the probability that a plate would be in the source category. Increased manganese content, in the range 0.30–0.65%, and finer grain size (larger grain-size numbers) or a decrease of plate thickness decreased the transition temperature but had relatively little effect on fracture initiation. It appears that in hot-rolled steels of this type the grain size is related primarily to the plate thickness, since an increase of plate thickness was equivalent in effect to a larger grain size with very little change in the coefficients for the other factors (Tables 5 and 6). Other elements present in only small amounts in these steels apparently had little effect.

10. It appears that a good correlation exists between the V-notch Charpy test results and the service-fracturing tendency of steel in World War II ships. However, care must be taken in extending this correlation to steels of different compositions or steels processed in different ways. In particular, increasing the manganese content may not reduce the tendency toward service failure to the same extent that it reduces the Charpy transition temperature.

Acknowledgment

Many organizations and individuals—too many to name and thank individually—have contributed to these investigations. The laboratory examinations and tests would be of relatively little value unless the laboratory results could be correlated with service experience. Collection of the ship-plate samples and of data on the service failures was made possible by the cooperation of the ship owners and operators, the U. S. Coast Guard, the Department of the Navy, the Maritime Administration and the American Bureau of Shipping. Much credit is due in particular to the Coast Guard inspectors who were responsible for the selection and identification of the samples and for obtaining detailed information regarding the casualties. The Ship Structure Committee has sponsored most of this work since July 1947. The Committee on Ship Steel has provided general advisory services, and, since June 1952, its Project Advisory Committee has given specific guidance for these studies. The early part of this investigation was conducted under the supervision of George A. Ellinger, who has continued to show an active interest in the project and has given valuable counsel throughout the investigation. Many fellow workers in the Metallurgy Division, the Specimen Shop, the Chemistry Division and the Statistical Engineering Section of the National Bureau of Standards have taken part in the laboratory work and in the analyses of the data. The author wishes to express his sincere thanks to all.

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ADVANCES IN WELDING AUSTENITIC MATERIALS IN THE CONSTRUCTION OF CHEMICAL APPARATUS AND TANKS

BY J. MUNDT

This paper discusses three fields in which full advantage has been taken of the outstanding ductility of austenitic steels. The first is the field of *low temperatures* in the liquefied gas industry. Ductility is measured with the round notch impact specimen, which yields over 20 mkg/cm² at −292° F for unwelded grades with the exception of the stabilized grades and particularly the grade containing molybdenum. Values of 12 to 14 mkg/cm² are obtained at −292° F with the molybdenum grade. The titanium-stabilized grade (X10 CrNiTi 189) is the subject of the following tests. Plates 0.59 in. thick were V-butt welded in the flat position with the electrodes in Table 1. In every instance the notch-impact value of the weld metal was lower than that of the plate. The heat-affected zone never had lower impact value than the weld metal. The drop in impact value was gradual as the temperature fell from room temperature to −292° F. The following conclusions emerged from about 100 tests.

Impact value was the same for welds made with $^1/_8$- and $^3/_{16}$-in. electrodes and for welds made in the flat position and "vertical up." With 4302 electrodes the highest impact values were secured with inert-arc welding, the lowest with submerged-arc welding. Covered electrodes were intermediate. The following values at −292° F were obtained with consumable-electrode inert-arc welding ($^1/_{16}$-in. electrode) at high travel speed: 9.1, 9.8, 11.4, 12.1, 15.1 and 16.5 mkg/cm². The cause of the variations is believed to lie in the variations in cooling rate. Slow cooling is

(*Continued on page 467-s*)

Abstract by **Gerard E. Claussen** of "Fortschritte bei Schweissungen mit Austenitischen Werkstoffen im Apparate- und Behalterbau," published in *Technische Mitteilungen Krupp*, **15**, 29-36 (1957). Dr. Claussen is associated with Linde Co., Newark, N. J.

Table 1—Austenitic Welding Electrodes

No.	*DIN 17006 type*	*Analysis of deposited metal, %*							*Average* notch impact value mkg/cm² at −292° F*
		C	*CR*	*Ni*	*Mo*	*Cb*	*Mn*	*Other*	
4302	X5 CrNi 189	0.06 max	18.0-20.0	8.5-10.5	...	...	1.5 max	...	About 6
4551	X10 CrNiNb 189	0.10 max	18.0-20.0	8.0-10.0	...	12 x C min	1.5 max	...	Less than 3
4402	X5 CrNiMo 1810	0.06 max	18.0-20.0	9.0-11.0	2.0-2.5	...	1.5 max	...	About 4
4597	X8 NiCrMoCuNb 2018	0.10 max	17.5-19.5	19.0-21.0	2.0-2.5	12 x C min	1.5 max	1.8-2.2 Cu	About 6
4842	X15 CrNiSi 2520	0.15 max	24.0-26.0	19.0-21.0	...	...	1.5 max	1.8-2.3 Si	Over 7
4225	X15 CrNiMn 188	0.10-0.20	17.0-19.0	8.0-9.0	...	...	5.5-6.5	...	Less than 3
4981	X12 CrNiNb 1717	0.12 max	About 17.0	About 17.0	About 1.8	10 x C min	...	...	About 5

* Manual covered electrodes.

TOUGHNESS OF WELDS EVALUATED SEPARATELY AND IN COMPOSITE

Investigation indicates that composite tests furnish significant data on the relative notch toughness of weld metal and heat-affected base metal

BY WILLIAM P. HATCH JR. AND CARL E. HARTBOWER

ABSTRACT The Watertown Arsenal Laboratories' composite test utilizes a V-notched Charpy impact specimen with approximately equal areas of weld metal and heat-affected base metal in the cross section under the notch. Because a definite relationship exists between lateral expansion occurring at the base of the Charpy specimen and the energy absorbed in fracturing the specimen, it is possible to substitute lateral expansion for energy in plotting transition curves. Thus, separate measurements of lateral expansion at the weld and heat-affected base-metal sides of the test specimen provide two distinct transition curves from a single set of specimens.

The objective of this investigation was to obtain further information on the significance of composite Charpy-impact tests by comparing transition curves of weld and heat-affected base metals tested separately and in combination. The findings confirm the validity and usefulness of the composite deformation-temperature transition curves for evaluating the relative toughness of weld and heat-affected base-metal structures. Moreover, the composite test method is versatile in that it permits the testing of a range of welding techniques (from stringer beads to multipass weaving in a V groove), and is economical in that it permits simultaneous evaluation of the notch toughness of weld metal and heat-affected base metal from one series of test bars.

Introduction

Background

A method for simultaneously evaluating the notch-toughness characteristics of weld metal and heat-affected base metal was introduced in a previous report.[1] Standard V-notched Charpy-impact specimens were machined from a bead-on-plate weldment in such a way that the cross section under the notch consisted of equal areas of weld metal and heat-affected base metal (Fig. 1). With the weld and heat-affected base metal areas symmetrically located with respect to the specimen centerline (centerline perpendicular to the V notch), it was possible to plot two transition curves from a single set of specimens by measuring the lateral expansion in each side of the composite-test specimen. In other words, by separate measurements of lateral expansions, transition curves for both weld metal and heat-affected base metal were obtained from a single set of specimens.

It was demonstrated in the report that by changing from an austenitic weld deposit to a relatively notch-sensitive ferritic weld deposit, it was possible to produce a marked shift in the deformation-temperature curve for the weld metal, while the curve for the heat-affected base metal was relatively unaffected (Fig. 2). On the basis of these and similar results, it was concluded that transition curves obtained from the composite specimen provide useful information as to the relative notch toughness of the weld-metal and heat-affected base-metal structures in a given weld joint.

In an attempt to learn more about the mechanics of flow and fracture in the

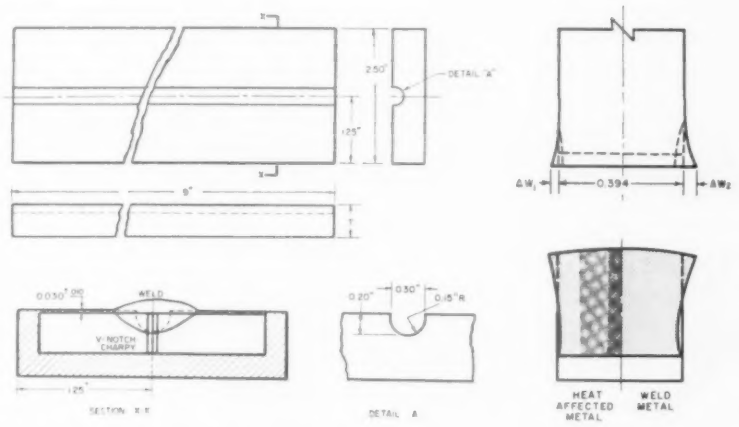

Fig. 1 Composite Charpy impact test

Illustration shows the test plate, orientation of test specimen and lateral expansion in a fractured test specimen

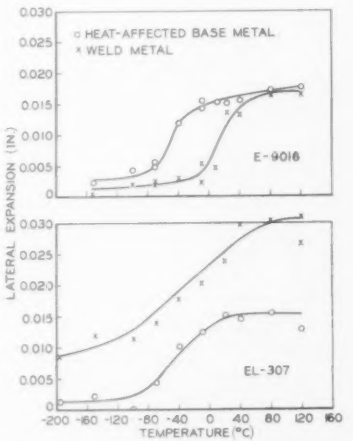

Fig. 2 Deformation-temperature transition curves

Composite specimen shows the relative toughness of two types of weld metal deposited in a single base metal. Note that the heat-affected base metal (o) was essentially unchanged in spite of the marked difference in toughness between the ferritic and austenitic weld deposits (x)

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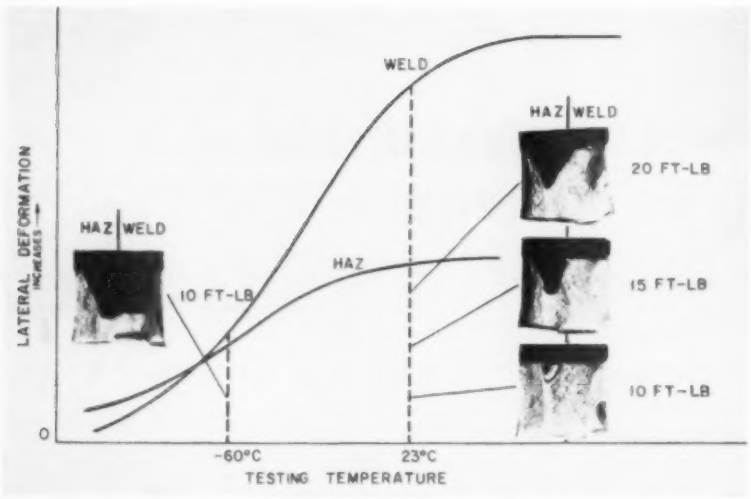


Fig. 3 Crack initiation and propagation as obtained by low-blow technique

By delivering a 10 ft-lb blow at room temperature, a crack was initiated in the most notch-sensitive component of the weld joint. The crack surfaces were stained with ink prior to the fracturing blow. Blows of 15 and 20 ft-lb caused deeper cracking (propagation) with the front of the fracture leading in the most notch-sensitive of the heat-affected-zone structures. At a lower temperature, the 10 ft-lb blow resulted in considerable propagation with a nearly square fracture front, indicating that both weld metal and heat-affected base metal had lost most of their resistance to crack propagation at the lower temperature (Reference 1). (HAZ = Heat-affected zone)

composite specimen, low-energy blows were used to initiate cracking. The crack surfaces were then stained with ink and the specimen fractured. Preliminary results indicated a good correlation between the results of the crack-initiation studies and the deformation-temperature transition curves for weld and heat-affected base metal (Fig. 3).

Questions have been raised as to whether deformation-temperature transition curves obtained from the composite test specimen are useful for predicting the relative (qualitative) toughness of weld and heat-affected base-metal structures in an actual welded joint. In an investigation of titanium and titanium alloys,[2] it was found that transition temperatures corresponding to 2% lateral expansion obtained from all-weld-metal specimens and from the weld-metal sides of composite Charpy specimens were for all practical purposes the same (±10° C).

Objective

The object of this investigation was to obtain further information on the significance of composite Charpy impact tests by comparing transition curves for weld metal and heat-affected base metal as obtained in separately tested

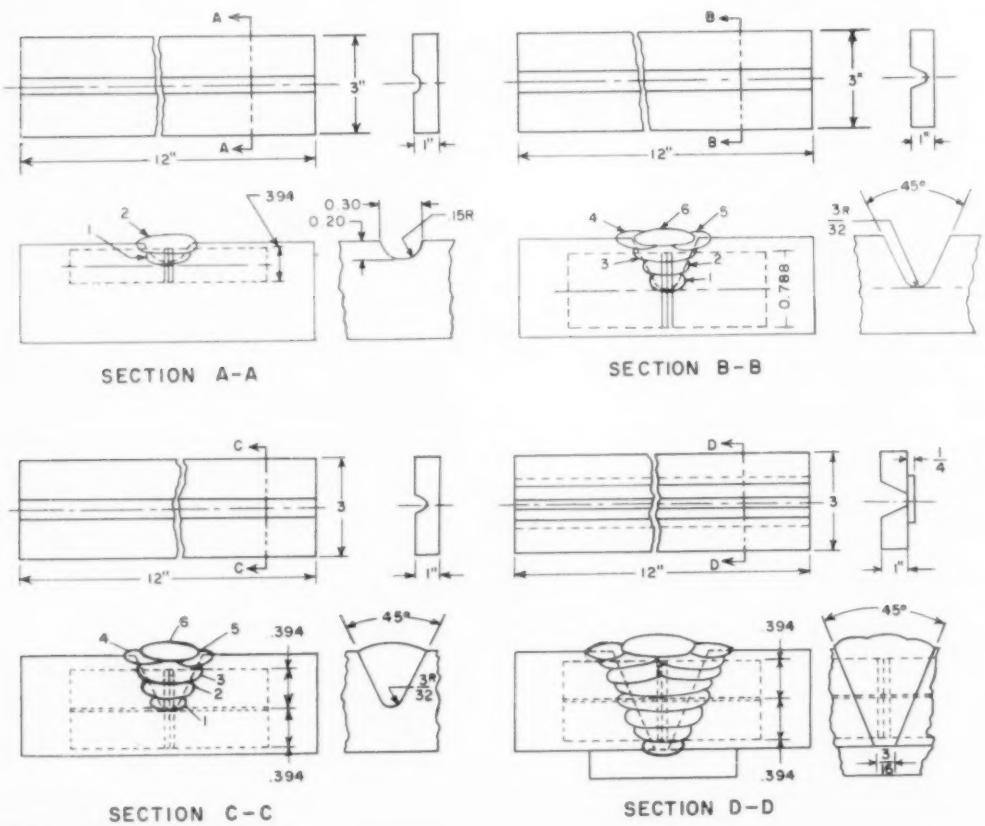


Fig. 4 Weldment and specimen details

Test plates, welding sequence and specimen orientations are shown for the standard- and double-width Charpy specimens used in this investigation

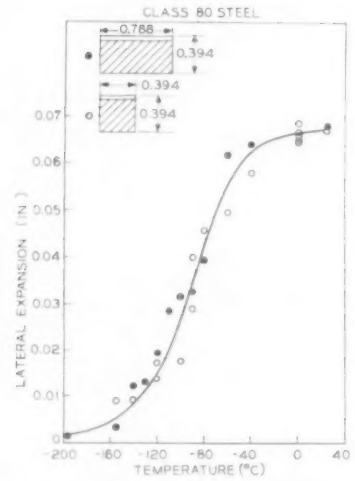


Fig. 5 Transition curve from standard- and double-width Charpy impact specimens

Conventionally obtained data (single full-capacity blow) from standard- and double-width V-notch Charpy impact specimens result in a single deformation-temperature transition curve. The superposition of deformation-temperature transition curves obtained from a single- and double-width specimen was previously observed in a nickel steel (see Fig. 8 of Reference 4)

specimens and in combination in the composite-test specimen.

Materials

The material used in this investigation was a low-alloy, high-tensile steel plate welded with low-hydrogen E10016 electrodes. The low-alloy steel plate was obtained from stock which had been purchased under U. S. Army Specification 57-114-3 (now MIL-E-13326 (ORD), Class 80). The composition and tensile properties of the plate were as follow:

Composition, wt %	
C	0.17
Mn	0.22
Si	0.23
S	0.030
P	0.011
Ni	2.13
Cr	0.97
Mo	0.22
V	0.03
Cu	0.057
Yield strength (0.1%), psi	79,300
Tensile strength, psi	101,700
Elongation, %	33.0

The electrode was Grade 230 ferritic, low-hydrogen type from a special lot of a commercial brand (with a single batch of coating and a single heat of core wire) purchased under Specification MIL-E-986. The composition and tensile properties of the deposited weld metal as determined by Watertown Arsenal Laboratories were as follows:

Composition, wt %	
C	0.06
Mn	0.80
Si	0.58
S	0.024
P	0.015
Ni	1.58
Cr	0.15
Mo	0.42
V	Trace
Yield strength, psi	95,000
Tensile strength, psi	105,000
Elongation (2 in.), %	23
Reduction of area, %	59

Procedure

The composite specimens were machined from test weldments (Fig. 4) in such a way that the cross section under the notch consisted of approximately equal areas of weld metal and heat-affected base metal. To make possible a comparison between composite tests and separate tests of deposited weld metal and heat-affected base metal, it was necessary to introduce a joint geometry which would permit (1) standard Charpy specimens to be cut from both the weld metal and the heat-affected base metal and (2) simultaneous testing

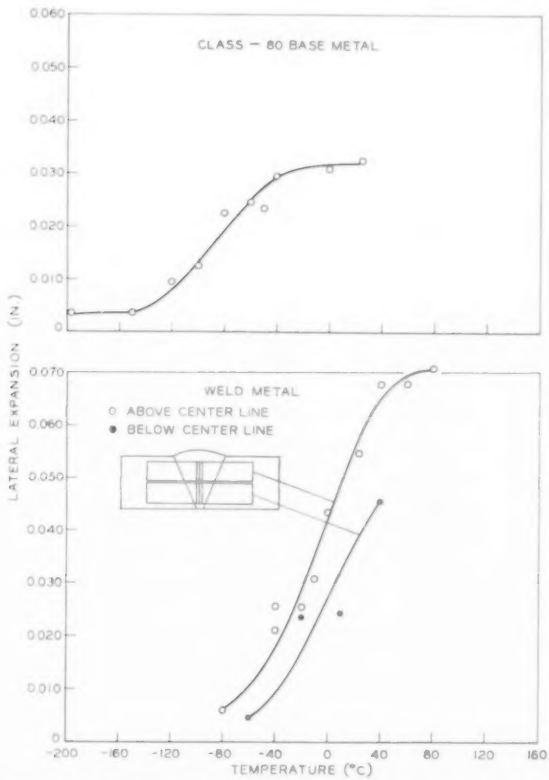


Fig. 6 Transition curves from standard Charpy tests of unwelded plate (upper curve) and weld metal (lower curves)

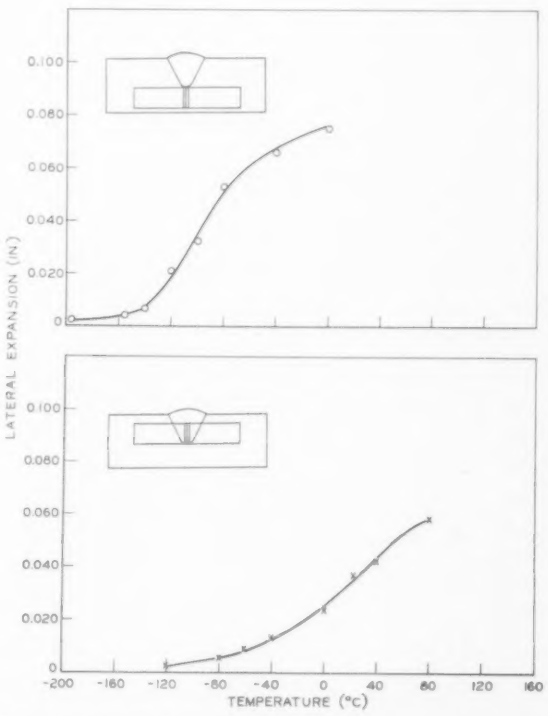
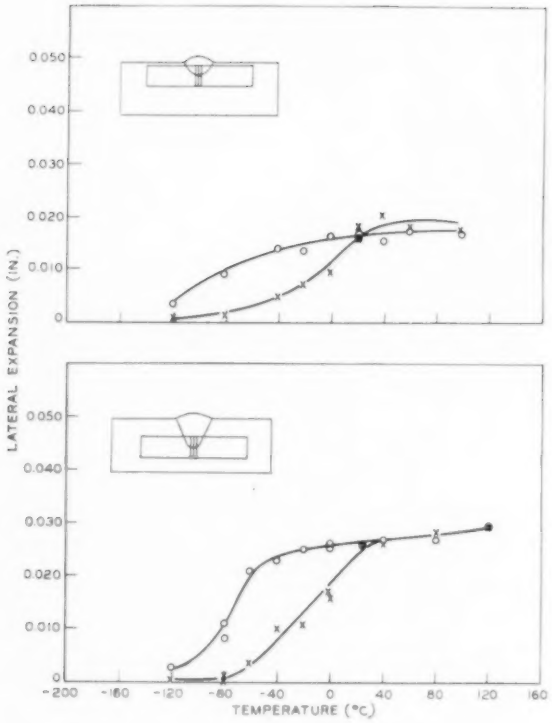


Fig. 7 Separately determined transition curves for heat-affected base metal (upper curve) and deposited weld metal (lower curve)



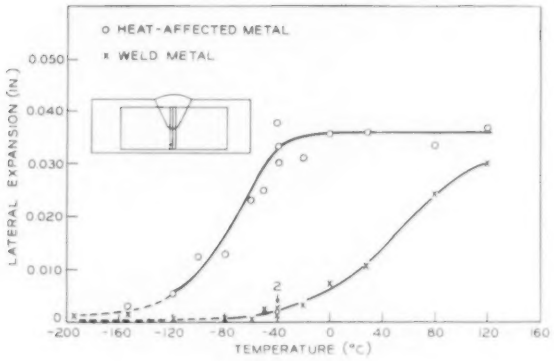


Fig. 8 Transition curves from standard- and double-width composite specimens

Note the displacements between the weld-metal and heat-affected base-metal transition curves for a given joint design and specimen width, and for different joint designs and different specimen widths

of weld and heat-affected base metal by means of a double-width composite specimen. A V-groove machined to a depth of $^1/_2$ in. in the 1-in. thick plate was selected for this purpose. Thus, it was possible to cut standard-width specimens from either the weld or heat-affected base-metal sides of the test plate, as well as double-width composite test specimens centered on the fusion line (Fig. 4).

The welding procedures used in preparing the test weldments are presented in Table 1. The 2-pass U-groove weld used for standard-width composite specimens is considered to approximate the case of a fillet weld; whereas, the 6-pass V-groove weld used for double-width composite specimens simulates one side of a double-V butt weld. In making the weldments, an attempt was made to maintain similar heat-affected zone structures; therefore, the same welding conditions were employed in depositing the first and second passes in all welds.

Standard-width Charpy bars for weld-metal tests were prepared from the V-groove and V-butt welds as shown in Sections C-C and D-D of Fig. 4. In the case of the V-butt weld, tests were conducted both in the lower portion of the V joint (where base-metal melting and multipass heat effects were most pronounced), and in the upper portion of the joint (above mid-thickness). Heat-affected base-metal specimens were taken just below the apex of the V-groove weld (see Section C-C of Fig. 4). Standard-width composite specimens were cut from the U groove, and both standard-width and double-width composite specimens were cut from the V-groove weldments (see Sections A-A and B-B of Fig. 4).

Table 1—Conditions Used for Producing Test Welds

	Weld joint type		
Conditions	*V-butt*	*U-groove*	*V-groove*
Number of passes	14	2	6
Number of layers	9	2	4
Pass number	1	1	1, 4, 5 and 6
Electrode size	$^5/_{32}$	$^5/_{32}$	$^5/_{32}$
Amperage (d-c RP)	180	180	180
Pass number	2 to 14	2	2 and 3
Electrode size	$^3/_{16}$	$^3/_{16}$	$^3/_{16}$
Amperage (d-c RP)	220	220	220

In general, energy measurements were not particularly useful in this investigation in that energy-temperature data as obtained from composite tests represent an integration of the toughness of the weld and heat-affected base metals. Such data, therefore, provide no direct information on the relative toughness of the weld and heat-affected base metals. Lateral-expansion measurements, on the other hand, were used extensively in this investigation. The usefulness of deformation-temperature transition curves was based on the following observations.

1. A definite relationship exists between the energy absorbed in fracturing a Charpy-impact specimen and the lateral expansion occurring in the sides of a broken specimen;[3] therefore, lateral expansion can be substituted for energy in plotting transition curves.

2. Lateral expansion can be measured in both the weld metal and heat-affected base-metal sides of the composite specimen, making it possible to obtain two transition curves from a single set of test specimens; thus, one curve indicates the transition behavior of the weld metal, and the other presents an integration of the transition behavior of the various heat-affected structures contained in the base-metal side of the test specimen (see Reference 1).

3. Plots of lateral expansion vs. testing temperature (Fig. 5) for standard- and double-width Charpy specimens superimpose;[4] thus, it is possible to make a direct comparison between the transition curves for weld metal and heat-affected base metal as determined separately from standard-width Charpy bars and as determined simultaneously from double-width composite specimens.

Discussion of Results

Toughness of Weld Metal and Unwelded Base Metal

The transition curves for the un-

welded base metal and the weld metal as deposited in a V-butt joint are presented in Fig. 6. It will be noted that transition temperatures based upon an arbitrary criterion of 0.010-in. lateral expansion indicate the unwelded base metal (−110° C) to be tougher than the weld metal (−40 to −60° C). The relative location of the two curves obtained from the V-butt weld indicates the weld metal in the bottom of the V joint to be somewhat more notch sensitive than that in the upper portion of the joint.

Toughness of Weld and Heat-Affected Base Metal Separately Determined

Figure 7 presents the transition curves for the weld metal as deposited in the V groove and the heat-affected base metal under the V groove. Again, using the same deformation level (0.010 in.) for purposes of comparison, the transition temperatures indicate the heat-affected base metal (−140° C) to be appreciably tougher than the weld metal (−50° C).

Comparison of Single- vs. Double-Width Composite Tests

Figure 8 presents the transition curves for weld metal and heat-affected base metal as determined from (1) single-width composite specimens cut from both the U-groove and V-groove weldments, and (2) double-width composite specimens cut from the V-groove weldments. In all cases, the ductile-to-brittle transition of heat-affected base metal occurs at a lower temperature than that of the weld metal. The following tabulation of approximate transition temperatures is based on a deformation level of 0.005 in.*

		Transition Temperature, ° C	
Joint	*Specimen*	*Weld Metal*	*Heat-affected zone*
U groove	Standard width	−40	−110
V groove	Standard width	−50	−100
V groove	Double width	−10	−120

It will be noted from the above tabulation that the heat-affected base-metal transition temperatures as measured in the single- and double-width composite specimens were not significantly different. This may be attributed to the fact that the *unwelded* base metal had approximately the same transition temperature (−110° C) as the integrated heat-affected base-metal structures; thus, it was indicated that welding was not especially detrimental to heat-affected-zone toughness in the particular base metal used. Likewise, the transition temperatures for weld metal as obtained from U-groove and V-groove standard-width composite specimens were not significantly different. However, the transition temperature for the weld metal in double-width composite specimen was 30 to 40° C higher than that in the standard-width composite specimens.

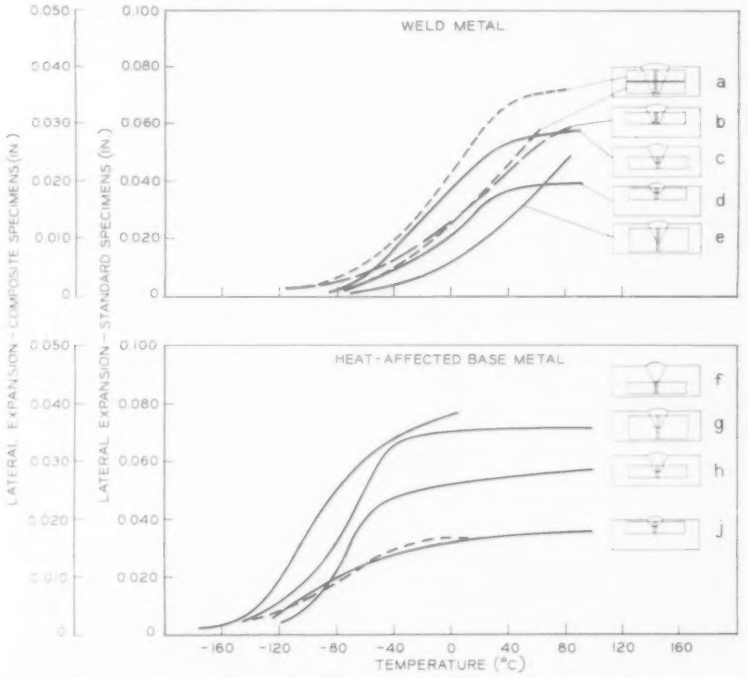


Fig. 9 Compilation of transition curves

Both composite-specimen test results and separately determined weld metal and heat-affected base-metal test results are included. The unwelded base-metal transition is shown by the dash curve in the lower figure

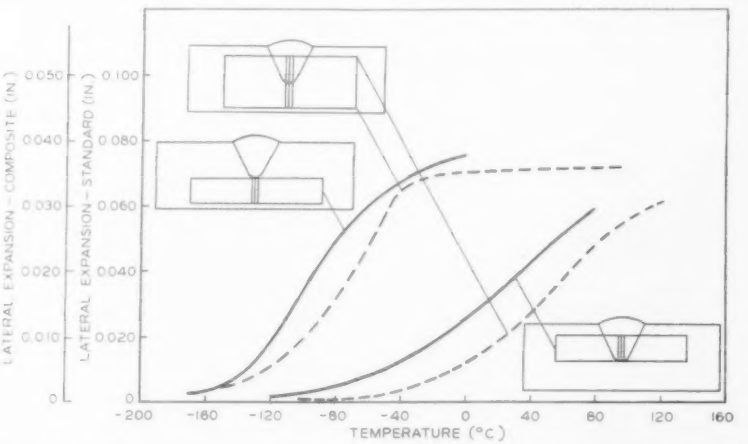


Fig. 10 Transition curves showing relationship between weld and heat-affected base metal tested separately with standard specimens and in combination with the double-width composite specimen

Total deformation was measured in "standard" specimens; whereas in double-width specimen, deformation was measured in each side (see footnote on this page)

* The deformation values reported for *composite* specimens represent measurements taken on one side of the specimen only, rather than the total expansion occurring in the specimen; consequently, the deformation (0.005 in.) used in determining transition temperature in composite specimens is ½ that used in connection with specimens containing either all weld metal or all heat-affected base metal in the cross section under the notch. It should be recalled (Fig. 5) in connection with the above tabulation that comparisons between lateral-expansion measurements in standard- and double-width Charpy bars indicate that the transition curves for the two sizes of specimen are superimposed; i.e., the values of lateral expansion as measured in standard- and double-width specimens are quantitatively the same. Thus, the same criterion of lateral expansion can be used for both single- and double-width specimens.

Comparison of Composite versus Separate Tests

Figure 9 represents the transition curves for (1) weld metal as obtained from all-weld-metal specimens and from composite specimens, and (2) heat-affected base metal as obtained from the heat-affected base-metal specimens and from the various composite specimens. The purpose of Fig. 9 (a compilation of curves from Figs. 6, 7 and 8) is to facilitate comparisons between the shapes and displacements of related transition curves. Note that when the same volumes of heat-affected metal were involved, there was little displacement in the low-temperature range of the transition curves. For example, in the case of the standard-width specimen (f) containing only heat-affected base metal and the double-width composite specimen (g), the test specimens contained the same heat-affected structures and produced very nearly the same transition temperatures.† Likewise, the V-groove (h) and U-groove (j) composite specimens which encompassed the same heat-affected structures also indicated very nearly the same transition temperatures. In the case of the weld metal, all but one of the transition curves were closely spaced in the low-temperature range ($-50 \pm 10°$ C). The exceptional performance occurred in the case of the double-width composite weld metal (e) with a transition temperature of $-10°$ C. Thus, it can be seen from Fig. 9 that in the case of either the weld metal or heat-affected base metal, displacements between the transition curves in the low-temperature (brittle fracture) range were, with one exception, not significant.

† Based on the amount of data and scatter involved, displacements of less than 20° C are not considered significant.

At higher temperatures where the curves are considered to reflect the relative resistances to ductile crack propagation, there was a marked difference in deformation levels. No explanation is offered for these differences. However, because of the greater deformation in the V-groove (6-pass) heat-affected base metal, it is suspected that multiple tempering effects may be involved.

The effects of testing weld metal and heat-affected base metal separately and in composite can be seen more clearly from the curves of Fig. 10. Note that the same weldment and, therefore, the same weld and heat-affected base-metal structures were tested in the composite specimens and in the standard-width specimens. Thus, any differences indicated between the double-width composite transition curves and those separately determined from single-width specimens cannot be attributed to metallurgical differences *per se*. Nevertheless, the curves of Fig. 10 indicate that (at any given temperature in the transition range) lower levels of deformation consistently attended failure of the weld and heat-affected metal structures when tested in composite than when tested separately.

One consideration that cannot be overlooked in comparing the curves obtained with single- and double-width specimens is the mechanical difference that exists between specimens of different size. In a Charpy test, the stress state is not uniform across the entire width of test specimen, i.e., the triaxiality which occurs just below the notch at midwidth of the test section decreases to a state of biaxiality at the free surfaces (sides) of the test specimen. Thus, in the composite specimen, microstructures located at the sides of the test specimen are subjected to only biaxial stressing. This geometrical factor could have an important bearing on results if a notch-sensitive structure happened to be located at or near a free surface (approximately 0.19 in. from the fusion line in a standard-width composite Charpy specimen). Likewise, in the separate tests of weld metal and heat-affected metal, this consideration could be important if the most notch-sensitive structure happened to be located either contiguous to the fusion line or at a distance of approx-

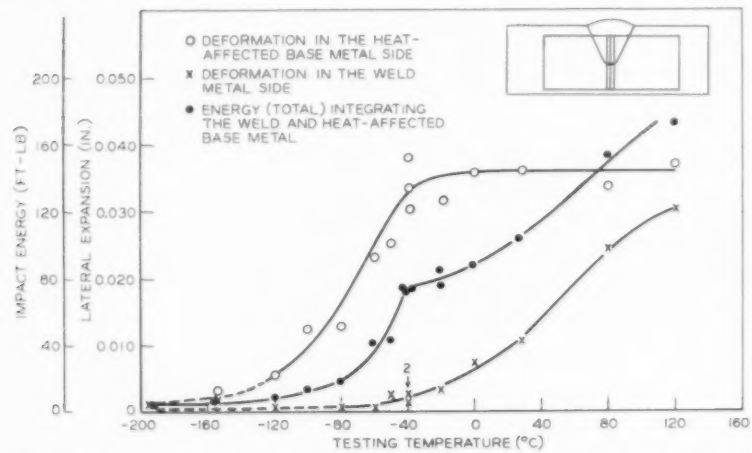


Fig. 11 Superposition of energy-temperature and deformation-temperature transition curves

The fact that the energy-temperature transition curve integrates the properties of weld and heat-affected base metal is demonstrated by he marked inflection in the energy-temperature curve

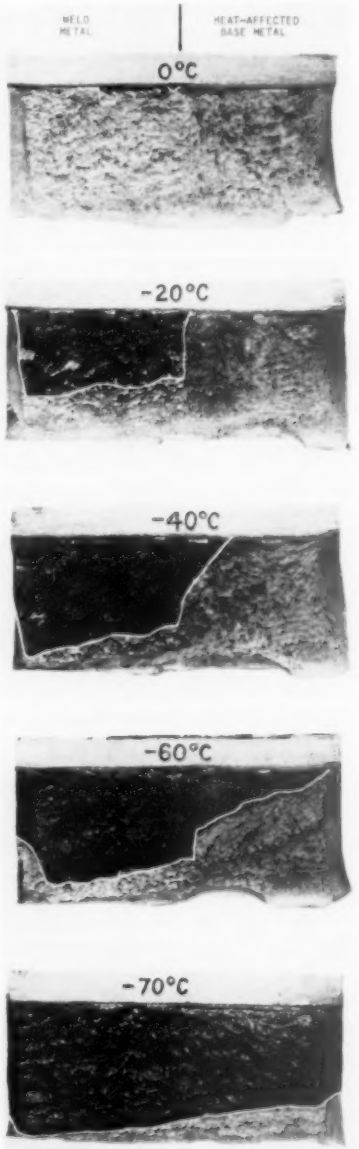


Fig. 12 Crack initiation and propagation in double-width composite specimens as produced by low blow at various temperatures

Ink staining consistently indicates that crack initiation occurred in the weld metal. To assure reproduction of the ink-stained areas, a white line has been drawn along the crack front

imately 0.39 in. from the fusion line. In the double-width composite test specimen, the chance of including critical notch-sensitive structures within the triaxially stressed region is improved over that in standard-width composite specimens simply because of the former's greater width.

Energy-Deformation Transitions in Double-Width Composite Specimens

The best evidence to date of the integrating effect of the composite test was obtained from a comparison between the energy-temperature and the deformation-temperature curves obtained from lateral-expansion measurements in the weld and heat-affected base metal sides of the double-width composite specimen (Fig. 11). Note that as the testing temperature was lowered to −40° C, the toughness of the heat-affected base metal was essentially constant, whereas the toughness of the weld metal was rapidly decreasing. At −40° C the toughness of the heat-affected base metal also began to decrease and, consequently, at −40° C an abrupt change occurred in the slope of the energy-temperature curve.

Crack Initiation and Propagation Studies

A technique for studying crack initiation and crack propagation in the composite specimen was proposed in an earlier report (Fig. 3). A preliminary low-energy blow is delivered to the test specimen by releasing the pendulum of a standard Charpy impact-testing machine from a calculated intermediate height. India ink, containing a wetting agent, is then placed in the notch; the ink flows by capillary action into the crack that may have developed as a result of the initial blow. The specimen is then fractured by a full-capacity blow of the pendulum. The location and extent of cracking produced by a given magnitude of blow is indicated by ink staining on the fracture surface. The minimum energy to initiate cracking is determined by using different magnitudes of low blow; the effect of testing temperature on the location and extent of cracking is determined by testing at each of several temperatures using the minimum energy to initiate cracking.

Double-width V-groove composite specimens when struck a low-blow of 30 ft-lb at 0° C produced a small but distinctly visible crack in the weld metal (Fig. 12). At −20 and −40° C the weld metal had lost most of its resistance to crack propagation, whereas the heat-affected base metal was, as yet, largely uncracked. In this connection, note from the deformation-temperature curve of Fig. 11 that at −20° C the lateral expansion in the weld-metal side of the double-width composite specimen fell to less than 0.005 in., whereas the deformation in the heat-affected base metal was

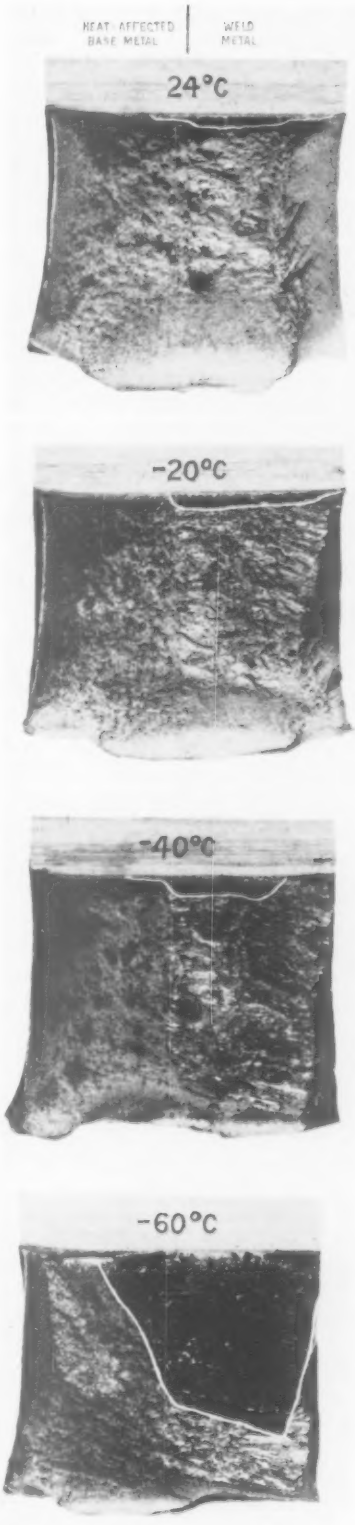


Fig. 13 Crack initiation and propagation in standard-width V-groove composite specimens

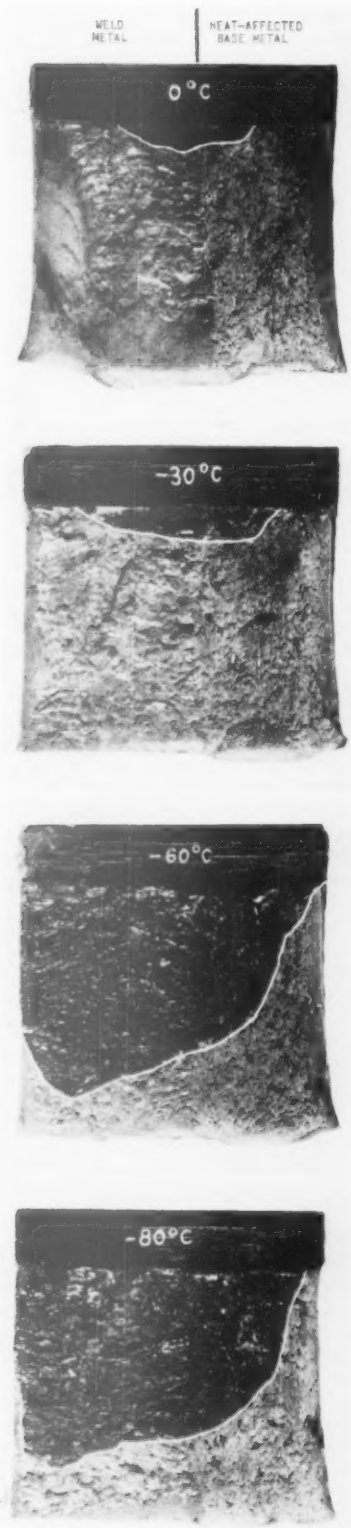


Fig. 14 Crack initiation and propagation in standard-width U-groove composite specimens

at a maximum. At −60° C the heat-affected base metal began to show pronounced cracking, and at −70° C the heat-affected base metal lost most of its resistance to crack propagation. At −80° C the composite specimen fractured under the initial 30 ft-lb low blow (brittle fracture of the weld joint as a whole).

Standard-width V-groove composite specimens, when struck a 15 ft-lb low blow, developed a small crack in the weld metal at +24, −20 and −40° C (Fig. 13). At −60° C the low-blow-induced crack extended deeply into the weld metal with only slight heat-affected base metal cracking. At −70 and −80° C the composite specimen fractured under the initial 15 ft-lb low blow. Standard-width U-groove composite specimens (Fig. 14), when struck a 15 ft-lb low blow at 0 and −30° C, developed a small crack on either side of the fusion line. At −60 and −80° C the low-blow-induced crack extended deeply into the weld and heat-affected base metals. At −100° C the composite specimen fractured under the initial 15 ft-lb low blow. A comparison between the above results and the relative positions of the deformation-temperature curves of Fig. 8 indicates an excellent correlation between the low-blow crack-propagation studies and the composite transition curves for *weld metal*. This is readily seen in the following tabulation which provides a comparison between the temperatures corresponding to the 0.005-in. deformation level and the temperatures of low blow producing extensive crack propagation (brittle fracture):

		Transition Temperature, ° C			
		Low blow causing extensive propagation		*At a deformation level of 0.005 in.*	
Joint groove	*Specimen width*	*Weld*	*Heat-affected zone*	*Weld*	*Heat-affected zone*
U	Standard	−30 to −60	−80 to −100	−40	−110
V	Standard	−40 to −60	−60 to − 70	−50	−100
V	Double	0 to −20	−60 to − 70	−10	−120

However, the temperatures corresponding to extensive crack propagation in the relatively tough heat-affected base metal did not correlate with the composite transition temperatures based on the 0.005-in. deformation level. Moreover, no single deformation level was found to correlate with the heat-affected base-metal crack-propagation temperatures.

Summary

The object of this investigation was to obtain further information on the significance of composite Charpy impact tests by comparing transition curves of weld and heat-affected base metals tested separately and in combination. Separate tests of weld and heat-affected base metal were accomplished by using a V groove machined to a depth equal to $\frac{1}{2}$ the plate thickness. The groove was filled with weld metal (6 passes), and standard Charpy specimens were taken from above and below the apex of the groove, thus providing two sets of specimens, one of which contained only weld metal in the test section and the other only heat-affected base metal. The testing of weld and heat-affected base metal in combination was accomplished by means of double-width specimens centered on the apex of the V groove. For additional comparisons, standard-width composite specimens were cut from the 6-pass V groove and also from a 2-pass U groove (the joint design used in developing the Watertown Arsenal Laboratories' composite specimen).

The transition curves from the U- and V-groove standard-width composite specimens and from the V-groove double-width composite specimen were consistent, showing the same relative toughness for the weld and heat-affected base metals. Likewise, transition temperatures, based on an arbitrary level of deformation (lateral expansion), produced a consistent trend as to the relative toughness of weld and heat-affected base metal. Moreover, heat-affected base-metal transition temperatures obtained with standard- and double-width composite specimens were practically the same (−110° C plus or minus 10° C), as were weld-metal transition temperatures determined from the standard-width U- and V-groove composite specimens (−40 and −50° C, respectively). The double-width composite specimen, on the other hand, indicated the transition temperature for weld metal to be 30 to 40° C higher than that of the standard-width composite specimens. The reason for the higher weld-metal transition temperature in the case of the double-width composite specimen was not determined, although metallurgical effects from multipass welding is suspected (explanation based on higher constraint in the double-width specimen was refuted when deformation-temperature transition curves from unwelded standard- and double-width Charpy bars were found to superimpose).

Separate tests of standard-width specimens containing only weld metal or heat-affected base metal in the test section confirmed the composite findings as to the relative toughness of weld and heat-affected base metal. Moreover, the deformation-temperature transition curves for heat-affected base metal, determined separately in a standard specimen and in combination with weld metal in a composite specimen, provided very nearly the same transition temperatures. In the case of the weld metal, the double-width composite specimen indicated a markedly higher transition temperature than the standard all-weld-metal specimen. Thus, the double-width composite test results were more conservative than the separate tests of weld and heat-affected base metal.

Low-blow crack initiation and propagation studies also confirmed the composite findings regarding the relative toughness of weld and heat-affected base metal. There was, in fact, an excellent correlation between the low-blow temperature producing extensive cracking (brittle fracture) in the weld metal and transition temperature based on the low-temperature portion of the composite deformation-temperature transition curves. However, the temperatures corresponding to extensive crack propagation in the relatively tough heat-affected base metal did not correlate with transition temperatures based on an arbitrarily selected deformation level.

Conclusions

From the findings of this investigation it is concluded that composite tests furnish significant data on the relative notch toughness of weld metal and heat-affected base metal. The test method is economical in that it allows simultaneous evaluation of the weld and heat-affected base metals, and, moreover, the test method is versatile in that it permits evaluations of weld and heat-affected base-metal structures produced by stringer-bead technique such as commonly used in depositing fillet welds or multipass weaving such as commonly used in groove joints.

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STUDIES OF STRESS-CORROSION CRACKING OF AUSTENITIC STAINLESS STEEL

Processes are described which lead to the inception and, in part at least, to the propagation of stress-corrosion cracks in austenitic stainless steel in a dilute chlorine-nitrite solution

BY HUGH L. LOGAN

ABSTRACT. Stress-corrosion cracking of Type 304 austenitic stainless steel has been produced by stressing sheet tensile specimens to their room-temperature yield strength in a boiling 0.5 *N* NaCl, 0.1 *N* $NaNO_2$ aqueous solution. Accelerated cracking of stressed specimens is accomplished by making them the anodes with an applied external current density of 0.03 to 1.0 ma/cm². Cathodic current densities of 0.04 ma/cm² or more protected the material against stress-corrosion cracking.

Material stressed to the room-temperature yield strength in the boiling solution continued to extend plastically (but non-uniformly with time) for at least 1 hr after the load was applied.

A film rupture mechanism for the inception of cracking is postulated.

Introduction

The National Bureau of Standards has in progress an investigation of the mechanism of stress-corrosion cracking of Types 304 and 304L austenitic stainless steels sponsored by the Pressure Vessel Research Committee. The results obtained in the early part of this investigation have been reported in an earlier paper.[1]

It has been reported that most service failures of austenitic stainless steels diagnosed as stress corrosion occurred in hot dilute chloride solutions. On the other hand, most of the corrodents used in laboratory tests, prior to the beginning of this investigation, had been concentrated chlorides. Those most commonly used were a 42% boiling magnesium chloride solution[2] or a 36% boiling calcium chloride solution.[3] The sponsors of the present investigation suggested, as a part of the problem, the development of a corroding medium that more nearly approximated the solutions which caused failures in service than the concentrated chlorides described above. The results, reported in the previous paper, indicated that dilute chlorides containing ammonium or sodium nitrite could be used successfully as a corrodent. Since this investigation was begun, work by Williams and Eckel[4] and by Edeleanu and Snowden[5] have indicated that stress-corrosion cracks could be produced in very dilute chloride solutions at high temperatures and pressures.

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Details of Investigation

Much of the early work at the National Bureau of Standards was carried out using a 3.5% sodium chloride, 1% commercial ammonium-nitrite solution. The commercial ammonium nitrite was a liquid containing only about 10% of the nitrite plus impurities and was difficult to obtain. Subsequently, the commercial nitrite was replaced by a solution containing 0.1 *N* NH_4Cl, 0.1 *N* $NaNO_2$ and 0.5 *N* NaCl. If a double decomposition occurred, the expected reaction was

$$NH_4Cl + NaNO_2 \rightarrow NaCl + NH_4NO_2$$

and the effective solution contained 0.1 *N* NH_4NO_2 + 0.6 *N* NaCl.

This solution proved effective in producing stress-corrosion cracking in the Type 304 stainless steel. The specimens from commercially annealed sheet stock were machined transverse to the direc-

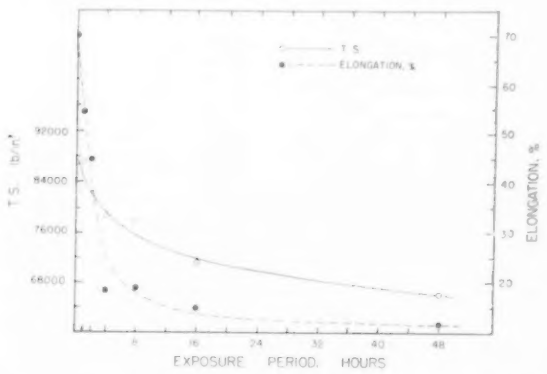

Fig. 1 Relationship between tensile strengths and percent elongation, and the exposure period for Type 304 stainless-steel specimens immersed in a boiling 0.5 *N* NaCl, 0.1 *N* NH_4Cl, 0.1 *N* $NaNO_2$ solution

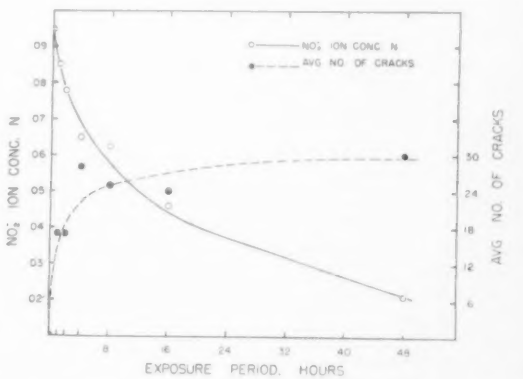

Fig. 2 Relationship between the concentration of NO_2^- ion and the average number of cracks formed and the exposure period for Type 304 stainless-steel specimens immersed in a boiling 0.5 *N* NaCl, 0.1 *N* NH_4Cl, 0.1 *N* $NaNO_2$ solution

tion of rolling. Prior to exposure they were pickled in a 12% HNO_3, 2% HF, 1% HCl solution at 80° C. After pickling and thorough rinsing, the specimens were placed in the corroding medium without being permitted to dry. Figure 1 gives the results of tensile tests made on specimens that had been stressed to 100% of their room-temperature yield strength (42,600 lb/in.²) in this boiling sodium chloride-ammonium nitrite solution for various exposure periods. It will be noted that the percent elongation and tensile strength of the corroded specimens decreased with the exposure period.

The changes with increased exposure period in both the number of cracks formed and the nitrite-ion concentration are shown in Fig. 2. The average number of cracks per specimen increased rapidly for the first 4 hr and thereafter did not change appreciably with time. The concentration of the nitrite ion, as determined in the cold solution at the conclusion of the exposure period, decreased with time. Mass spectrograph analyses of gaseous products from the corroding process had shown that the amounts of nitrogen increased with the exposure. There was no evidence that oxides of nitrogen were formed and it is postulated that the ammonium nitrite broke down in accordance with the following equation:

$$NH_4NO_2 \rightarrow N_2 + 2H_2O$$

Early results had indicated that sodium nitrite might be used instead of the ammonium nitrite. Further investigations showed that a boiling sodium chloride-sodium nitrite solution could produce stress-corrosion cracks in Types 304 and 304L stainless steel, as is shown in Fig. 3. The decreases in tensile strength and elongation of specimens stressed in a boiling NaCl + $NaNO_2$ solution for 48 hr were approximately the same as those obtained on specimens stressed to the same value in the NaCl + $NaNO_2$ + NH_4Cl solution (Fig. 1) for the same period of time. Analyses of many solutions made at room temperature after the conclusion of the exposure period indicated no decomposition of the nitrite ion. Accordingly, a 0.5 *N* NaCl, 0.1 *N* $NaNO_2$ boiling aqueous solution is currently being used as the corrodent. Neither the sodium nitrite nor the sodium chloride used separately in the concentrations given above produced stress-corrosion cracking in the Type 304 material at the stress level noted.

Hoar and Hines[6] reported that wire specimens exposed in boiling 42% $MgCl_2$ solution and loaded only during the latter part of the exposure period failed in approximately the same time as those that had been loaded from the beginning of the period. These data were important in the development of some of the current theories of the stress-corrosion cracking of austenitic stainless steels. Hence, it seemed important to check their results using the techniques developed in this investigation. Three groups of specimens (3 or 4 in each group) were stressed immediately after the NaCl + $NaNO_2$ had begun to boil. After 2 hr the stress was removed, but the specimens remained in the solution for an additional 46 hr. Three other groups of specimens were treated conversely. That is, they were exposed, unstressed in the same boiling corrodent for 46 hr and were then loaded to the same stress level as the first groups of specimens for the last 2 hr of the exposure period. All of the specimens were subsequently broken in tensile tests. The average values of the tensile strengths and elongations of 9 specimens, loaded during the first 2 hr of the exposure period and then unloaded but left in the boiling solution for 46 hr, were 71,500 lb/in.² and 16½%, respectively. The corresponding values for 12 specimens exposed in the boiling solution for 46 hr unstressed, then stressed for the final 2 hr of the exposure period were 85,700 lb/in.² and 52%.

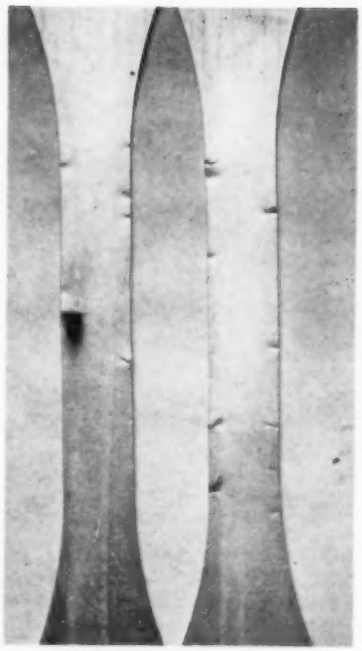

Fig. 3 Reduced sections of Type 304 stainless-steel specimens after exposure for 150 hr in boiling 0.5 *N* NaCl, 0.1 *N* $NaNO_2$ solution. X 1

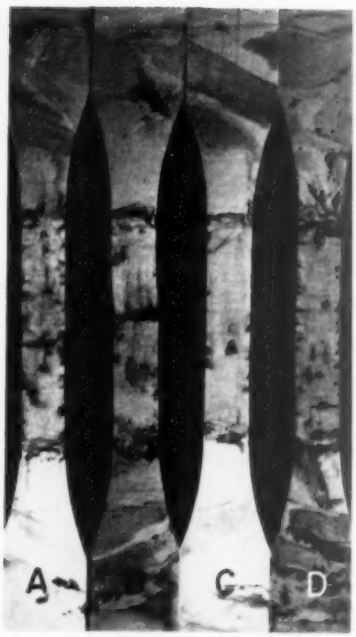

Fig. 4 Specimens of Type 304 stainless steel exposed in the boiling 0.5 *N* NaCl, 0.1 *N* $NaNO_2$ solution under stress equal to the room-temperature yield strength. Specimens were anodes in externally applied circuits. Current densities were: A, 1 ma/cm²; B, 0.5 ma/cm²; C, 0.1 ma/cm²; D, 0.03 ma/cm². A, B and D broke in less than 16 hr; C was removed after 16 hr. X ½ (approx.)

Effects of Corrosion Products

It has been suggested that the hydrolysis of corrosion products formed in stress-corrosion cracks may be a contributing factor in the propagation of such cracks in austenitic stainless steels. The resistance of Type 304 sheet and 304L rod to general corrosion (in the unstressed condition) was determined in solutions of compounds that could be formed during chloride corrosion of these steels. The concentrations of the various salts used, their pH values and the results of exposure for approximately 5 hr in the boiling solutions are given in Table 1. It is seen that pitting was produced only by $FeCl_3$ + NaOH at a pH of less than 5 and by $FeCl_2$ + HCl with a pH of 1.3. Other compounds such as $NiCl_2$, $CrCl_3$ and $MnCl_2$ which might possibly be formed during corrosion did not produce pitting at the concentrations and pH values used. However, if the specimen was made the anode in any of these solutions or in the NaCl + $NaNO_2$ solution and an external current was applied, the anode was pitted. Furthermore, if the anode and cathode were placed in separate compartments and connected through a semipermeable membrane, the pH of the solution decreased in the anode compartment as was to be expected from theory. In no case, however, was a specimen uniformly corroded; there were many areas that remained passive and showed no evidence of macroscopic pitting under the most severe corrosive

Table 1—Results of Exposure of Unstressed Type 304 Stainless Steel to Boiling Corrodents

Corrodent	*Concentration*	*pH, beginning of test*	*pH, end of test*	*Type of attack*
$FeCl_3$	1.0 *N*	1.9	1.7	Severe pitting
$FeCl_3$	1.0 *N* + NaOH	2.6	2.4	Severe pitting
$FeCl_3$	1.0 *N* + NaOH	4.0	3.8	Few large pits
$FeCl_3$	1.0 *N* + NaOH	4.5	4.3	Few pits
$FeCl_3$	1.0 *N* + NaOH	6.2	5.8	No attack
$FeCl_2$	0.1 *N*	3.5	2.8	No attack
$FeCl_2$	1.0 *N*	2.5	2.1	No attack
$FeCl_2$	1.0 *N* + HCl	1.3	1.1	Few pits
$NiCl_2$	0.1 *N*	5.1	5.1	No attack
$NiCl_2$	1.0 *N*	4.0	3.9	No attack
$CrCl_2$	0.1 *N*	3.0	2.9	No attack
$CrCl_2$	1.0 *N*	2.6	1.5	No attack
$MnCl_2$	1.0 *N*	4.4	3.3	No attack

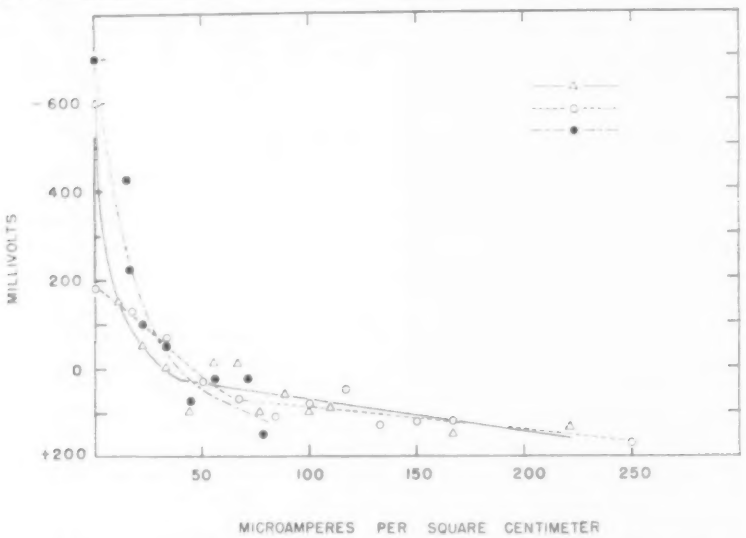

Fig. 5 Anodic polarization curves for three Type 304L stainless-steel specimens in a boiling 0.5 *N* NaCl + 0.1 *N* $NaNO_2$ solution. Voltages were determined using a saturated calomel electrode

conditions listed above. This is well illustrated in Fig. 4. These specimens were stressed to approximately 42,600 lb/in.² in the boiling NaCl + $NaNO_2$ solution. External currents ranging from 0.03 to 1.0 ma per cm² were applied to the systems, the specimens being the anodes. Results obtained on these and other similar specimens definitely indicate that stress corrosion can be accelerated by anodic currents in the range given above.

Polarization Curves

Anodic polarization curves have been obtained on a number of unstressed rods of the 304L composition in the boiling NaCl + $NaNO_2$ solution. Data from 3 typical specimens are shown in Fig. 5. It was assumed that the changes in slope of these curves were indicative of the beginning of corrosion. The current densities shown in the figure were computed from the total exposed area of the specimens. However, there was appreciable corrosion on only very limited areas and on the basis of these small areas, the current densities believed to produce this corrosion were calculated to have a minimum value of 5 ma/cm². It can be shown that this current would produce a crack penetration of 0.06 mm/hr. This rate of crack penetration is of the order of magnitude required to account for most of the stress-corrosion cracking observed in the NaCl + $NaNO_2$ solution.

Typical cathodic polarization curves are shown in Fig. 6. It is seen that there is a break in each curve corresponding to a current density of about 0.04 ma/cm². This would indicate that cathodic protection could be obtained in this solution at a current density of 0.04 ma/cm² or more. Experimentally, no stress-corrosion cracking was observed in specimens protected with a cathodic current density in this range.

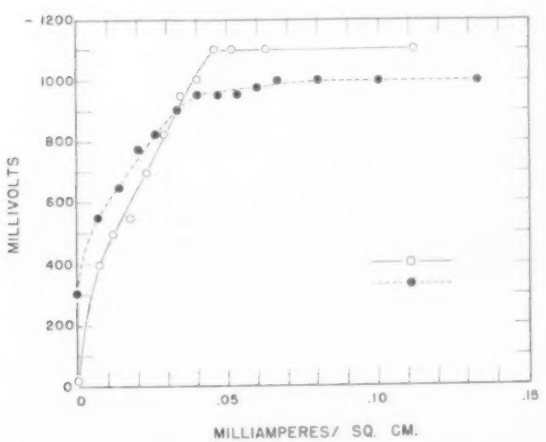

Fig. 6 Cathodic polarization curves for two Type 304L stainless-steel specimens in a boiling 0.5 *N* NaCl + 0.1 *N* $NaNO_2$ solution. Voltages were determined using a saturated calomel electrode

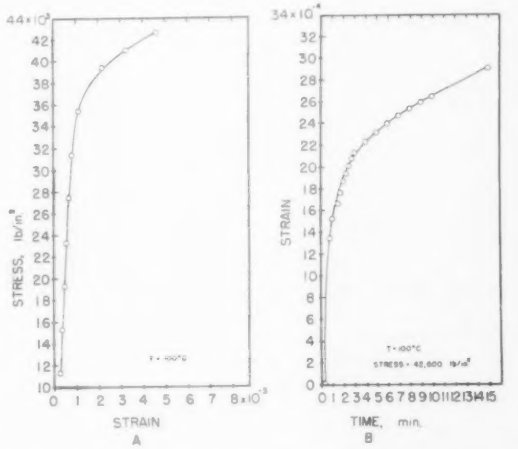

Fig. 7 A, stress-strain curve for transverse specimen of Type 304 stainless steel immersed in boiling distilled water B, strain-time curve for specimen at constant stress in boiling distilled water

The fact that stress-corrosion cracking can be accelerated by making the specimen the anode in the corrodent and can be prevented if the specimen is the cathode very definitely indicates that an electrochemical process is involved in the mechanism of stress-corrosion cracking.

Effects of Strain

The data reported in this present paper were obtained on commercially annealed sheet material stressed to its average room-temperature yield strength (42,600 lb/in²). Yield strengths of specimens determined subsequent to their exposure in the boiling corrodent were generally between 50,000 and 60,000 lb/in². This indicates that the material had been cold worked as the result of stressing. Accordingly, several determinations were made of the yield strength of the material in boiling distilled water, using wire strain gages. Values thus obtained were 5 to 15% less than those obtained at room temperatures (25 to 30°C). A typical stress-strain curve is shown in Fig. 7*A*. The strain values reported were determined as soon after load increments had been added as was possible. At the higher stresses, the strain increased with time following the increase in the stress. A strain-time curve for a specimen subjected to a stress of 42,600 lb/in² is shown in Fig. 7*B*. The strain gages failed after 15 min. These data have been supplemented using dial gages actuated by the loading lever used in stressing specimens. Using this method, it was estimated that at the end of 1 hr under stress a specimen was creeping at the average rate of 30×10^{-6} per min. This average creep rate, however, gives a very erroneous picture of what was actually happening. The dial-gage reading would remain constant for periods as long as 15 to 30 sec at one time and would then change several divisions in a very short time interval (Fig. 8). Simultaneous reading on two gages, actuated independently, indicated that this was a real phenomenon and not due to gage friction. In the earlier work, a variation of as much as 50% was found in the extensions, in 0.2-in. gage lengths, of individual specimens subjected to stresses of 80% or more of the room-temperature yield strength. Hence, it is only logical to assume that these sporadic increases in length are confined to short sections of the specimen and are not uniformly distributed throughout the entire gage length. If this creeping of the stressed specimen is not uniform but, at specific instances, is concentrated in relatively short lengths of the specimen, it will rupture the protective (passive) film on certain crystal faces. In earlier work, the film-free metal was shown to be approximately 0.315 v anodic to the filmed surface.[7] Hence, a galvanic cell will be set up in the corrodent, the film-free area being a small anode and the film-covered surface forming a large cathode. This is the condition for rapid attack at the anode. However, as the strain rate in this specific area decreases, a film repair process will tend once more to form a passive surface on the crystal and further corrosive attack will be less rapid. If, however, conditions existing in this crystal and its environment are such that it can be strained more readily than neighboring crystals there may be repeated rupturing and repairing of the film on the crystal surface with the corrosive attack going deeper each time the film is ruptured. The development of a groove in the crystal surface, normal to the applied stress, will (*a*) act as a line of stress concentration that will tend to increase the frequency of the film rupture cycle and (*b*) tend to trap solution, adjacent to the anode, with a lower pH than that of the corrodent as a whole. Once the pH of the solution at this point falls below 5, it will tend to slow down but not necessarily prevent the reformation of the passive film. It is postulated that the processes described above lead to the inception and, in part at least, to the propagation of stress-corrosion cracks in austenitic stainless steel in a dilute chloride nitrite solution.

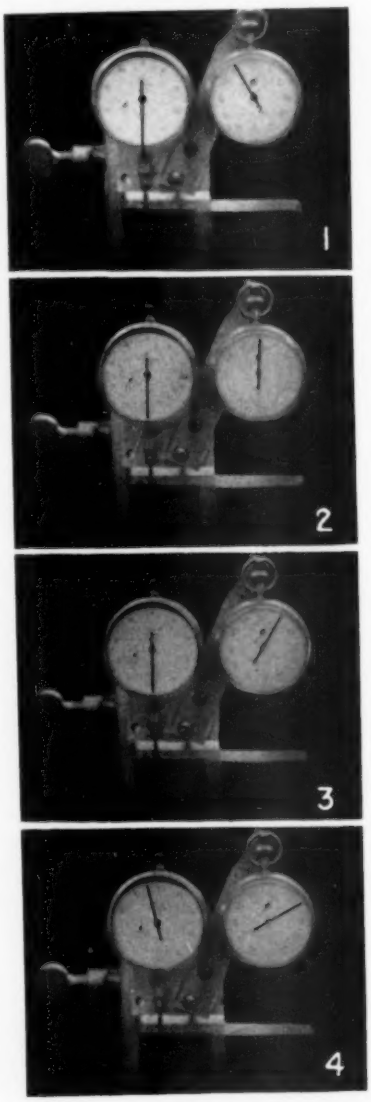

Fig. 8 Successive dial gage-stop watch reading showing extension of specimen is nonuniform with time. Dial gage was unchanged in 10-sec interval from frame 1 to 3. In the 5-sec interval from frame 3 to 4, dial gage reading changed approximately 0.0055 in. in a counterclockwise direction, 1 revolution being 0.01 in. Dial gage was actuated by the lever used in stressing specimen

Summary

1. Stress corrosion cracking of Types 304 and 304L austenitic stainless steels has been produced in boiling solutions containing 0.5 *N* NaCl + 0.1 *N* NH_4Cl + 0.1 *N* $NaNO_2$ or 0.5 *N* NaCl + 0.1 *N* $NaNO_2$.

2. The tensile strength and elongation of specimens stressed at the room-temperature yield strength for periods up to 48 hr in the NaCl + NH_4Cl + $NaNO_2$ solution and the nitrite-ion concentration of the solution decreased with increased exposure period. The number of cracks per specimen increased rapidly for the first 4 hr of exposure and thereafter did not change appreciably with time.

3. There was no decrease in the nitrite-ion concentration in 48-hr exposure periods using the boiling NaCl + $NaNO_2$ solution as the corrodent.

4. Macroscopic evidence of corrosion of Type 304L stainless-steel specimens, immersed unstressed in normal solutions of boiling $FeCl_3$, $FeCl_2$, $FeCl_2$ + HCl, $NiCl_2$, $CrCl_3$ and $MnCl_2$, was found only in those exposed in the $FeCl_3$ solutions having a pH of less than 5 and in the $FeCl_2$ + HCl solution with a pH of 1.3.

5. Accelerated stress-corrosion cracking could be produced in the NaCl + $NaNO_2$ solution by making the stressed steel the anode in an external circuit with a current density of 0.03 to 1.0 ma/cm².

6. From experimental data and cathodic polarization curves, it was found that a current density of approximately 0.04 ma/cm² or more (approximately 0.04 amp/ft²) would cathodically protect the material against stress-corrosion cracking.

7. The yield strength of the material was 5 to 15% lower at 100° C than at room temperature, 25–30° C. Specimens stressed to their room-tempera-

ture yield strengths continued to elongate for at least 1 hr after the stress was applied. The strain rate was nonuniform with time.

8. It is postulated that stress-corrosion cracking is electrochemical in its inception and in part, at least, in its propagation. Sporadic but repeated creep of material in certain favorably oriented regions ruptures the protective film on the metal in narrow areas, normal to the applied stress. The film-free area is a small anode; the cathode area is very large and corrosion is rapid until the film reforms. This eventually produces a condition of stress concentration, normal to the applied stress that plays an important part in the propagation of stress-corrosion cracking.

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ADVANCES IN WELDING AUSTENITIC MATERIALS IN THE CONSTRUCTION OF CHEMICAL APPARATUS AND TANKS

(Continued from page 454-s)

believed to account for the low impact values with submerged-arc welding. Impact value was not changed by peening with an air hammer at room temperature or at 932° F.

A plate welded with 4302 electrodes was annealed at 1922° F and was quenched in water. Over the range, room temperature to −292° F, the impact value was raised about 2 mkg/cm². The value at −292° F was raised 3.8 mkg/cm² averaged over ten specimens for a similarly heat-treated plate welded with 4551 electrodes. Despite the low notch-impact results for 4551, a cylindrical tank welded with 4551 was sucked in by vacuum at −292° F with no damage.

The second field is the *welding of clad steel*. The old method of welding with removal of cladding has been displaced by the method involving preliminary removal of cladding developed by the American petroleum industry. Ordinarily there is no difficulty in meeting side bend requirements with the American method. In one instance of welding mild steel clad with 13% chromium steel with 4551 electrodes, cracks occurred at the junction of the weld metal with a thin layer of Monel that was used to bond the cladding to the mild steel. This difficulty was overcome with 4842 electrodes, which however, are not stabilized. Great care is required with 4581 electrodes to avoid these cracks.

The third field is the automatic *weld cladding of mild steel equipment*. The cladding of the inside of a thick walled pipe 24 in. ID over a length of 6½ ft will be described. The pipe was preheated to avoid cracks. The first layer was deposited with 4225 electrode to equalize stresses. Several layers of 4581 electrodes then were deposited. With manual welding it is customary to clad with the successive longitudinal beads spaced 90 deg apart to avoid distortion. With automatic welding the bead is a continuous helix along the inside circumference. Consumable-electrode welding was used with a travel speed of 24 ipm using argon containing 1% oxygen. A constant potential generator was used. About 22 lb of wire was deposited per hr. Deeper penetration and greater dilation were experienced on reverse polarity than on straight polarity.

CORROSION OF ZIRCALOY-2 SHEET WELDMENTS

Experimental data show that Zircaloy-2 sheet can be welded in air with simple precautions without sacrificing bend ductility or resistance to corrosion in 680° F water

BY R. STEIN AND R. E. MONROE

ABSTRACT. Studies of fabrication and welding procedures for reactor fuel elements consisting of UO_2 plates jacketed in Zircaloy-2 sheet were conducted. Emphasis was placed on determining the suitability of economic welding techniques for joining Zircaloy-2. Comparison of bend ductility and corrosion properties showed no differences in weldments made in air with inert-gas shielding and weldments made in an inert-gas-filled vacuum-purged dry box. Weight gains of all corrosion samples were about the same. Fabrication, property, and procedure data are reported.

Introduction

The realization of economical commercial atomic power requires careful study to select the cheapest fabrication procedures consistent with stringent safety requirements. A portion of such studies conducted for the Atomic Power Equipment Department, General Electric Co. was designed to study fabrication and joining procedures for producing fuel elements for the Dual-Cycle Boiling Water Reactor.[1] Of particular interest, was a fuel element consisting of UO_2 plates contained in a thin Zircaloy-2 jacket for protection against corrosion by the water coolant. An individual element of this type might measure ½ in. x 4 in. x 12 ft.

The jacketing studies were started before the final fuel-element design was established so it was necessary to obtain data which could be used with a number of possible designs. On this basis, considerable work was done on tungsten-arc welding of Zircaloy-2 in air with various shielding arrangements and in a vacuum-purged dry box. The purpose of this work was to determine whether corrosion properties and weldment properties could be maintained if welding were done in air. Contamination of weldments made in air by oxygen or nitrogen would be reflected in lowered bend ductility and lowered corrosion resistance.

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Weldments made in 0.02-in. thick Zircaloy-2 sheet with various shielding methods were subjected to bend and corrosion tests. The bend ductility of all weldments was better than the ductility of unwelded sheet stock. Corrosion studies in 680° F degassed water for 245 days showed no significant differences between any of the weldments and unwelded stock. The average weight gain during this time was 70 mg/dm². These results show that excellent Zircaloy-2 weldment properties can be obtained without resorting to the use of dry-box systems.

In order to present as complete a picture as possible, all the data available on the Zircaloy-2 sheet material used in this program are included in this paper. These data include fabrication procedures, chemical analyses, mechanical properties and metallographic studies.

Material

The Zircaloy-2 sheet used in the corrosion studies was rolled during the experimental program. Therefore, the fabrication schedule for this sheet is given in this section. A number of studies related to the properties and forming characteristics of this sheet also were made during the program. These studies are also reported since they compliment the corrosion data.

Fabrication

Reactor-grade Zircaloy-2 for use in this work was purchased as a 3-in. square billet and fabricated into sheet at Battelle. The procedure used to fabricate the sheet material is given in Table 1. This procedure may not represent optimum conditions, but its use was necessary to obtain sheet in the time available. All rolling was done with 10% reduction per pass. One mil was pickled off the surfaces of the sheet after rolling to give a final thickness of 0.020 in. For annealing during processing, the sheet was heated in vacuum in a large retort. The maximum pressure during these annealing treatments was 3 microns of mercury. Samples of appropriate dimensions were sheared from the sheet material.

Table 1—Fabrication Procedure for Zircaloy-2 Sheet

(1)	Forged to 1¼ by 4-in. sheet bar at 1750° F
(2)	Rolled to 0.35 in. thick at 1750 to 1600° F
(3)	Rolled to 0.14 in. thick at 1550° F
(4)	Sheet cleaned for cold rolling by pickling in 50 vol % H_2O, 45 vol % HNO_3, 5 vol % HF
(5)	Rolled to 0.090 in. thick at 80° F*
(6)	Annealed 1 hr at 1550° F in vacuum
(7)	Rolled to 0.070 in. thick at 80° F*
(8)	Rolled to 0.028 in. thick at 1000° F
(9)	Step (4) repeated
(10)	Annealed 1 hr at 1550° F in vaccum
(11)	Rolled to 0.021 in. thick at 80° F

* Rolling discontinued because of edge cracking.

Chemical Analysis

The chemical analysis of the Zircaloy-2 material is given in Table 2.

Table 2—Chemical Composition of Zircaloy-2

	Analysis, wt %	
Spectrographic	*Chemical*	*Vacuum fusion*
Mg 0.032	Sn 1.53	O_2 0.077 ± 0.002
Fe 0.10	N_2 0.003	H_2 0.0039 ± 0.0002
Cr 0.09	C 0.015	
Ni 0.043		

The composition given agrees with previously reported analyses[2] of reactor-grade Zircaloy-2.

Bend Tests

Initial bend tests of the as-rolled sheet indicated that the material could not be

formed to the desired jacket shapes. A series of heat-treating procedures was investigated to produce material that would accept bends equal to twice the sheet thickness without fracturing. The as-rolled sheet contained a fine precipitate of the complex intermetallic compound of zirconium plus nickel, iron and chromium. Low bend ductility has been attributed to the presence of this precipitate in previous investigations.[3] Heating between 1400 and 1600° F, followed by water quenching, was found to dissolve this precipitate and retain it in solution with a subsequent improvement in bend ductility.

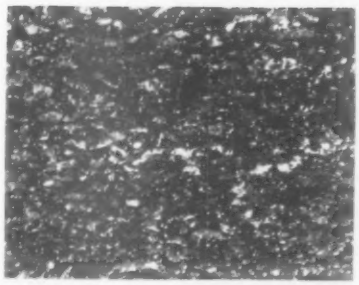
Rectangular specimens 0.02- x 0.5- by 1.5-in. cut parallel and perpendicular to the rolling direction were used in the bend tests. After shearing to size, the edges of the specimen were filed smooth to eliminate notches. Next, 0.001 in. was removed from the specimen surfaces (0.0005 in. per side) by pickling in a 50 vol % H_2O, 45 vol % HNO_3, 5 vol % HF solution.

Specimens were bent to conform to radii equal to one, two, three or four times the sheet thickness. A 5000-lb dynamometer testing machine was used to deform the specimens by pressing a steel tup against a $\frac{3}{8}$-in. thick neoprene pad. A maximum load of 500 lb was required to insure the sheet conformed to the tup radius. Bend ductility results are given as the smallest radius in terms of sheet thickness that will form sheet without failure.

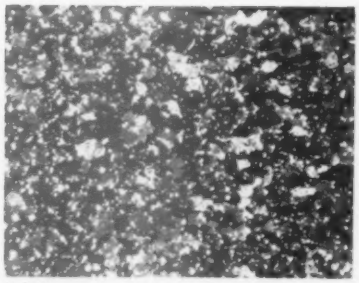
The effects of various heat treatments on bend ductility are summarized in Table 3. The test results show that heat treatment below 1600° F gives only minor improvement of bend ductility as compared with the bend ductility of the as-rolled sheet. This improvement was probably due to recrystallization and

Table 3—Summary of Bend Data

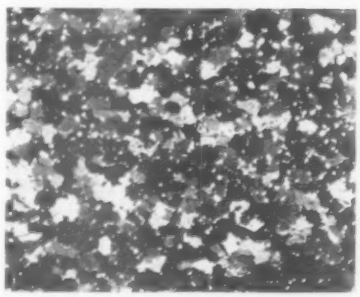
Heat treatment	*Number of samples*	*—Relative— ductility Perpendicular to rolling direction*	*Parallel to rolling direction*
As rolled	3	...	4T
	1	4T	...
In helium 1 hr at 1200° F, water quenched	3	...	4T
	3	4T	...
In helium 1 hr at 1550° F, water quenched	2	...	4T
	2	4T	...
In helium 30 min at 1750° F, water quenched	8	3T	...
In helium or argon 30 min at 1800° F, water quenched	10	2T	...



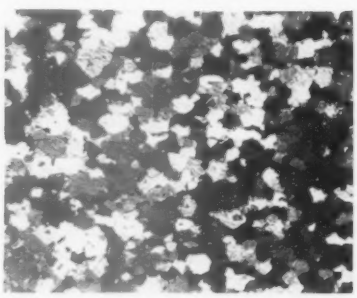
X 100
Polarized light—as rolled



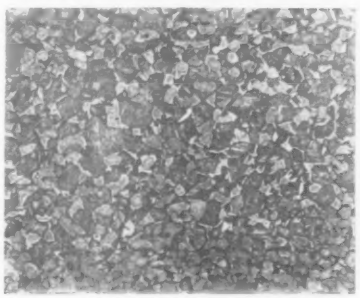
X 100
Polarized light—1 hr at 1200° F



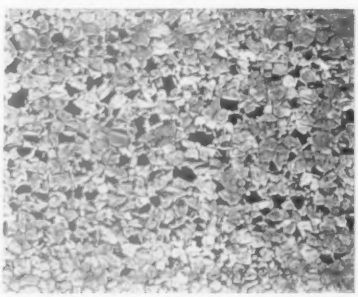
X 100
Polarized light—1 hr at 1550° F



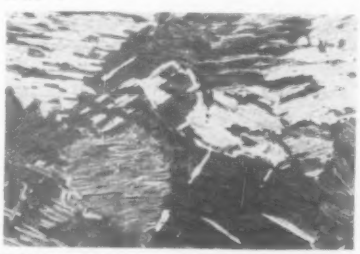
X 100
Polarized light—1 hr at 1600° F



X 100
5 vol % $NH_4F \cdot HF$, 95 vol % H_2O—30 min at 1750° F



X 100
5 vol % $NH_4 \cdot HF$, 95 vol % H_2O—30 min at 1775° F



X 100
5 vol % $NH_4 \cdot HF$, 95 vol % H_2O—30 min at 1800° F

Fig. 1. Microstructure of Zircaloy-2 sheet after soak at temperature followed by water quench. (The small white dots are the precipitates referred to in the text)

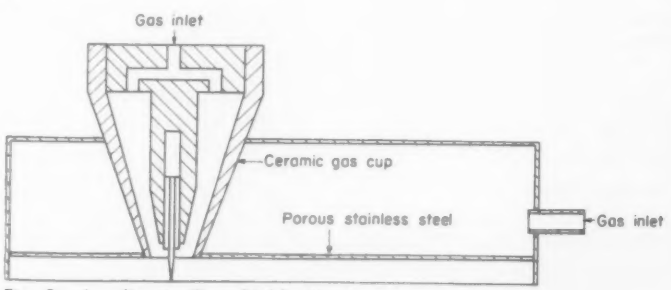


Fig. 2. Leading-trailing shield unit

elimination of residual stresses. Subsequent heat treatments at 1800° F, followed by a water quench, gave specimens that would bend consistently to a 2T radius without failure.

Metallographic Studies

Metallographic examinations were made to supplement the bend tests on heat-treated samples. As mentioned earlier, the precipitate found in the as-rolled sheet is a complex intermetallic compound of zirconium plus nickel, iron and chromium. The effects of heat treatments between 1200 and 1800° F on this precipitate are shown in Fig. 1. A small amount of the precipitate existed in specimens heat treated below 1600° F. The precipitate tended to agglomerate along grain boundaries as the temperature of the heat treatment was increased. After a 1600° F treatment, very little of the precipitate is visible. This is expected since the intermetallic compounds of zirconium and nickel, iron and chromium form eutectoids at about 1500° F and can be retained in solid solution by fast quenching. Failure to retain completely the precipitate in solution was reflected in the bend tests, which showed only minor improvement in ductility after heat treating up to 1600° F, followed by a water quench, as compared with the ductility of as-rolled sheet.

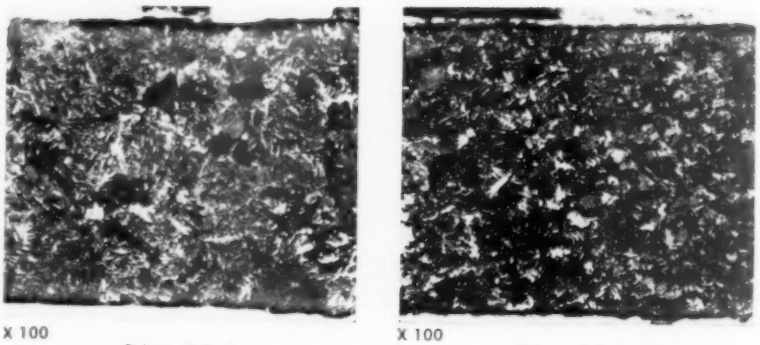
Subsequent heat treatments above 1600° F, followed by a water quench, produced microstructures with no visible sign of precipitate. Heat treating in helium or argon for 30 min at 1750° F, followed by a water-quench, produced alpha plus transformed-beta structures. A transformed beta structure was obtained by heat treating at 1800° F for 30 min, followed by a water quench. Bend specimens with this type of microstructure gave the greatest bend ductility.

Tension Tests

A limited number of tension tests were made on standard sheet specimens[4] with a 2-in. gage length. SR-4 strain gages were used to determine strain values, and the yield points were measured at 0.2% offset. These data are shown in Table 4. Specimens CK50C and CK50D were twisted during their heat treatments, and stresses other than uniaxial probably were superimposed during loading. This may account for the difference in yield strength between these two specimens. It appears that heat treating below 1600° F did not appreciably change the strength of the heat-treated specimens from the as-rolled strengths.

Weldment Preparation

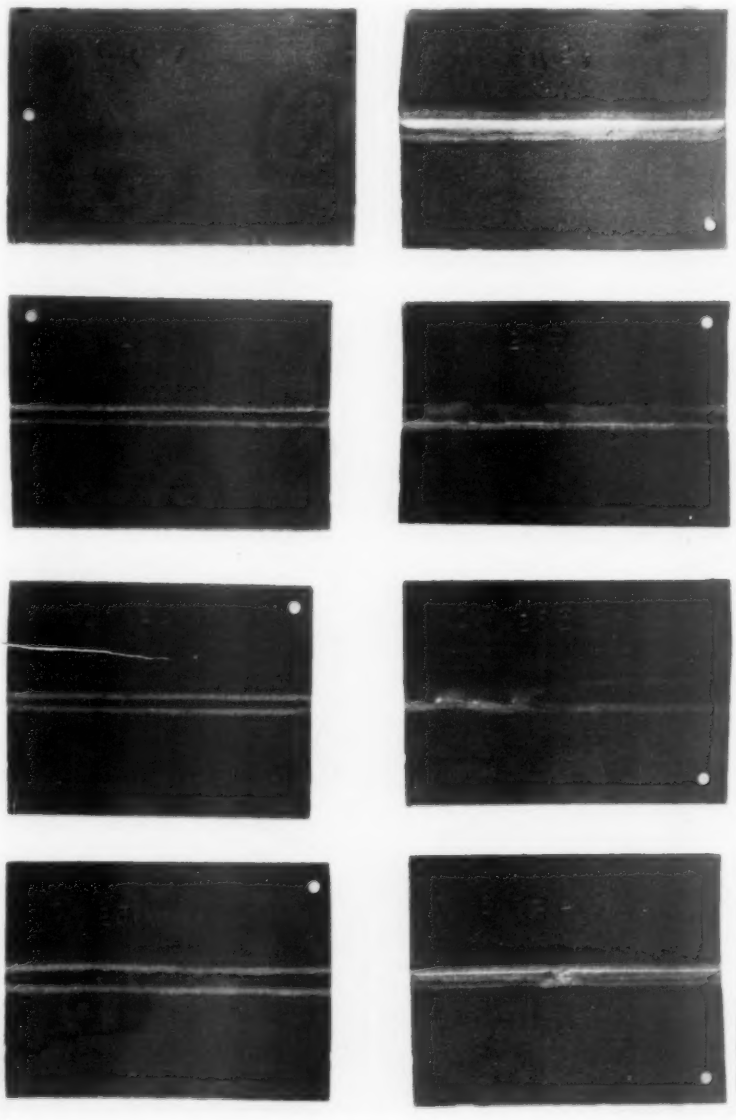
Sealing of flat-plate fuel element clad with 0.02-in. thick Zircaloy-2 jackets would involve welding a number of long seams. Machine welding using the tungsten-arc process probably would be the



X 100 Polarized light Weld zone

X 100 Polarized light Heat-affected zone

Fig. 3 Microstructure of weld and heat-affected zones in fusion-welded Zircaloy-2 sheet



X 1

Fig. 4 Zircaloy-2 samples after corrosion test

best method of sealing these seams. With proper jigging, production of such welds would be relatively simple, except for the necessity of preventing contamination of large Zircaloy-2 components. The use of conventional dry-box welding methods would be undesirable in production of large flat-plate fuel elements. As mentioned before, the welding of Zircaloy-2 in air may cause weldment contamination and result in lower bend ductility and corrosion resistance. Therefore, test evaluations were made on square-butt joints to establish the effects of various shielding methods on these factors.

The shielding methods studied included a vacuum-purged dry box for baseline data, standard inert-gas-shielding cups with $^3/_8$- and $^5/_8$-in. diam orifices, and a leading-trailing shield unit.

Equipment and Procedures

Grade-A helium gas was used to shield all welds. The dry box used in this investigation has been described previously.[5] Helium was admitted to the dry-box chamber directly from a high-pressure cylinder after vacuum purging to 0.1 micron of mercury. This technique insures atmosphere gas purity equal to the purity of the gas in the cylinder.

The ceramic shielding cups used in air were standard commercial parts. The leading-trailing shield unit shown in Fig. 2 was designed to provide additional protection on both sides of the weld area. Flowing gas also was used to protect the root side of the weld joint. This gas was supplied through a porous baffle plate which extended the full length of the weldment.

Machine welding with an electronic arc-voltage control or a fixed torch was used for all welds. The Zircaloy-2 sheets were clamped over the gas backing with copper chill plates. Welding power was supplied by standard three-phase d-c rectifiers. Preweld cleaning consisted of etching in 50 vol % H_2O, 45 vol % HNO_3, 5 vol % HF followed by water and acetone rinses.

Some weldments were made using a square-butt joint design in the 0.020-in. thick sheet. Samples for bend tests, corrosion studies and hardness surveys were cut from each weld. The corrosion samples were degreased and pickled in a 50 vol % H_2O, 45 vol % HNO_3, 5 vol % HF solution before testing.

Weldment Properties

Various weld settings, given later, were used to produce acceptable weldment geometry with full-weld penetration. Bend tests made on longitudinal and transverse bend specimens, welded in air and using a standard $^3/_8$ in. ceramic shielding cup, showed no detrimental effects due to weldment contamination. The minimum bend ductility in both directions was consistently 2T. This was better than the bend ductility of the unwelded sheet (annealed in helium 1 hr at 1200° F and water quenched) which was only 4T. These results appear incongruous, especially for bend ductility perpendicular to the weld. However, examination of the weld microstructure showed the same type of structure typical of sheet with the best ductility obtained by heat treatments. Figure 3 shows the microstructure in the weld and heat-affected zones. Both zones consist of transformed beta, the only difference being grain size, which is much larger in the weld zone. The corrosion studies were made in degassed water at 680° F. Pertinent data from these studies are given in Table 5. Slight contamination of the welds made in air with oxygen or nitrogen may be indicated by the small increase in weld-metal hardness.

Observation of the corrosion specimens during and after exposure revealed a tan oxide film in the weldment heat-affected zone. For some of these specimens, this tan oxide film was also evident in the weld zone, as shown in Fig. 4. Comparison of the weight gains of the specimens welded under various shielding arrangements and unwelded sheet showed no significant difference in the corrosion properties. This is graphically illustrated in Fig. 5 which shows that, after 245 days of testing, the maximum difference in total weight gain between the various samples is only 8 mg

Table 4—Summary of Tension Tests

Heat treatment	*Specimen*	*Yield strength, psi*	*Ultimate strength, psi*	*Elongation in 2 in., %*
As rolled	CK50B	50,500	63,270	18.2
In vacuum 1 hr at 1550° F, furnace cooled	CK50C	44,500	62,600	20.6
	CK50D	52,500	65,630	21.0
In vacuum 24 hr at 1550° F, furnace cooled	CK50E	50,000	61,270	18.7
	CK50F	49,500	62,500	19.3
In helium 1 hr at 1200° F, water quenched	CK50G	47,500	63,600	23.2
In helium 1 hr at 1550° F, water quenched	CK50H	48,500	65,800	17.5
Average		48,900	63,500	19.8

Table 5—Summary of Data for Corrosion-Test Specimens

	Specimen								
	—*CK21B*—		*CK22A*	—*CK25A*—		—*CK26A*—		—*CK27A*—	
	1	*2*		*1*	*2*	*1*	*2*	*1*	*2*
Welding conditions									
Current, amp.	16		12	12		24			
Arc voltage, v	25		22	23		20		Unwelded	
Travel speed, ipm	12		12	12		72			
Shielding conditions									
Nozzle diameter, in.	Vacuum-		$^5/_8$	$^3/_8$		$^3/_8$			
Nozzle height, in.	purged dry		0.16	0.04		0.04			
Helium-flow rate, cfh	box filled								
Nozzle	with Grade		40	40		40			
Backing	A helium		20	20		20			
Trailing shield	(0.1 μ)		..	40		40			
Average Knoop hardness*									
Weld	200		..	..		209		210†	
Heat-affected zone	202		..	..		196		..	
Weight gain after number of days indicated, mg per dm²									
14	13	14	14	11	15	12	12	13	135
28	17	17	18	15	18	17	17	17	140‡
56	25	26	26	24	27	31	26	27	
84	28	32	32	30	36	36	33	34	
112	38	44	44	43	48	55	49	46	
147	47	52	52	53	57	57	57	50	
161	49	54	55	58	59	60	59	52	
189	53	57	58	60	61	63	62	54	
196	53	57	58	59	61	62	62	55	
224	63	64	64	65	71	69	69	64	
245	63	67	69	71	71	74	72	69	

* 500-kg load.

† Hardness of as-rolled sheet.

‡ Specimen removed from test.

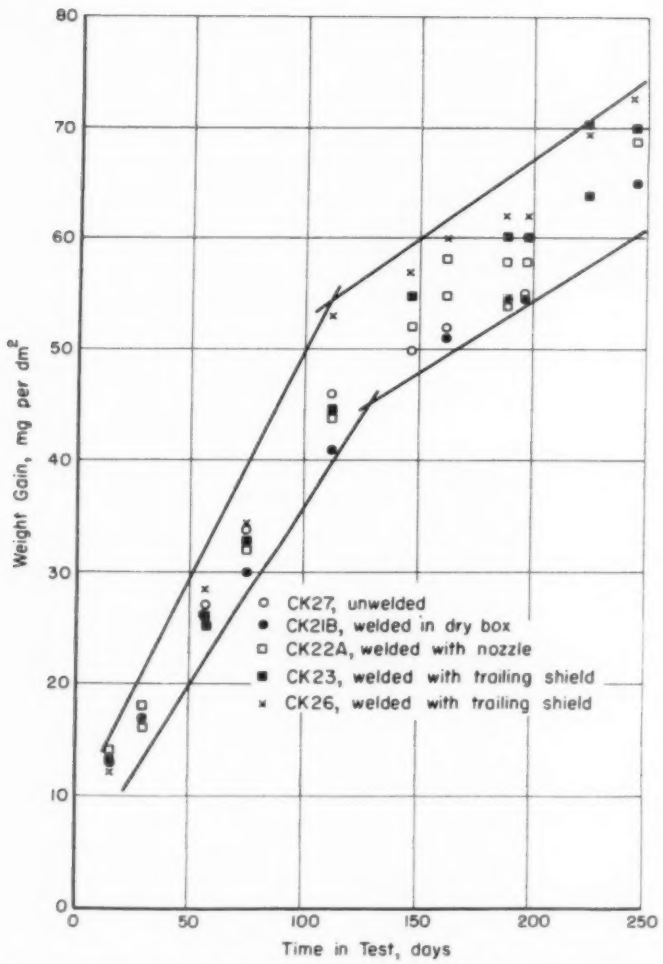

Weight Gain, mg per dm²
Time in Test, days
CK27, unwelded
CK21B, welded in dry box
CK22A, welded with nozzle
CK23, welded with trailing shield
CK26, welded with trailing shield

Fig. 5 Weight gain during corrosion test in 680° F degassed water

per dm.[2] However, since the welds represent only about 5% of the total specimen area, it is felt that more significance should be placed on the fact that all of the samples did not show any indication of a white oxide film. Existence of a white oxide film on Zircaloy-2 generally indicates that the material is approaching corrosion failure.

The small percentages of weld surface of the sample probably prevented any noticeable difference in corrosion rate between the welded samples and the unwelded control sample. A slightly higher corrosion rate is expected in Zircaloy-2 on material which has been treated to eliminate the intermetallic precipitate usually found in the alpha-phase microstructure.[2] As shown earlier, this precipitate was not present in the weld or heat-affected zones of these weldments.

Corrosion of Zircaloy-2 generally follows a characteristic curve which can be divided into 3 stages:[6] (1) a rapid weight gain accompanying oxide formation in the first few days of exposure, (2) a gradual increase in weight gain to about 100 days' exposure, and (3) an increased rate of weight gain after approximately 100 days' exposure. The point at which the change between the second and third stages occurs is referred to as the transition point. The data reported do not show a typical transition point and indicate that corrosion was still occurring by the mechanism dominant in the second stage when exposure was discontinued. The slope of the corrosion curve for these data throughout the entire test period agrees with the slope given by Misch,[6] 0.33, for the second stage of the characteristic curve. No explanation for the lack of starting of third stage corrosion has been found, but it does not affect the data for comparisons of shielding effects up to 245 days' exposure. However, it should be pointed out that significant differences in the various samples might exist over longer exposure time.

Conclusions

The experimental data show that Zircaloy-2 sheet can be welded in air with simple precautions without sacrificing bend ductility or resistance to corrosion in 680° F water. Although a single sheet thickness and joint design were used in this work, the data should be applicable to other thicknesses and weldment configurations.

Acknowledgment

This work was supported by the Atomic Power Equipment Division, General Electric Co. The help supplied by this group during the investigation and their gratuitous permission to publish these results is greatly appreciated. The advice in planning and in conducting the welding and corrosion studies given by D. C. Martin and W. K. Boyd, respectively, contributed greatly to this program.

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STATIC BRITTLE-FRACTURE INITIATION AT NET STRESS 40% OF YIELD

Brittle fracture of unwelded steel plate is initiated for the first time in the laboratory under controlled conditions at average net stresses well below yield level

BY C. MYLONAS, D. C. DRUCKER AND J. D. BRUNTON

ABSTRACT. Static fractures which are brittle from the start are evidence of lack of ductility at the point of crack initiation and occur at low average net stress. Past static tests, in failing generally to reproduce the phenomenon of brittle-fracture initiation, showed that undamaged steel plate under adverse notch conditions has sufficient ductility to allow general yielding before fracturing. Static initiation of brittle fracture can be achieved by an additional exhaustion of ductility. For this purpose, a steel of high transition temperature was subjected to various types of prestraining. The best results were achieved by precompressing 3/4-in. thick 10-in. square plates with machined notches so as to produce large plastic strains at the notch roots.

When tested in central static tension at a temperature below the transition range, these plates fractured at average net stresses well below yield level. The lowest average stress at fracture was 36% of virgin yield. Thus, for the first time brittle fracture of unwelded steel plate has been initiated in the laboratory under controlled conditions at such low stress. The conditions at fracture indicate that energy theories are useless or inapplicable in the problem of fracture initiation. Finally, residual stresses are shown to be of little importance when ductility is ample. When embrittlement is excessive, they only hasten a fracture which would have occurred at low applied stress in the absence of residual stress.

Introduction

The problem of the brittle fracture of steels which, under the usual favorable circumstances, appear to have sufficient strength and ductility, is far from solved or even clearly understood. Several theories have been proposed on this subject, but all have serious limitations.* Thus, it has been found in practice and confirmed by theory that the severity of a notch enhances the occurrence of brittle fracture. It has also been shown that a statistical correlation exists between the temperature of steel at the time the fracture starts and the empirical standard of brittle transition temperature (especially as defined by energy absorption in the Charpy V-notch impact test). These results have helped select better steels and improve design and fabrication procedures so as to reduce significantly the occurrence of brittle fracture.[3, 4]

Nevertheless, several important points remain to be explained.[1–3] One of them is the equivocal behavior of steel with respect to the initiation of brittle fracture as distinct from its propagation. Experiments,[5–7] as well as actual fractures, have shown that a crack once started will, under suitable conditions, propagate at high speed at nominal stress levels considerably smaller than yield and lower than the nominal stresses present in many successfully operating structures.[1–6] However, contrary to all theories of the Griffith type, centrally loaded symmetrical plates of sound steel, having even the longest and sharpest cracks and temperatures below brittle transition, generally were not found to fracture before the average stress over the net section reached yield level[1–3, 11] and appreciable plastic deformation occurred,[1–3] unless an exceptionally severe impact was produced at the notch[5, 6] or an artificially highly embrittled area facilitated the initiation of cracking.[5, 7]

The conditions of initiation of actual in-service fractures were different, however. The over-all stresses clearly were well below yield in some instances[12] and the evidence is strong that they were low in many of the service failures. Furthermore, as a rule, there is little visible plastic deformation[1–3] in the region of fracture initiation.

The inability of notched plates of sound steel to fracture statically in the laboratory at net average stresses below yield has sometimes led to the opinion that high over-all stresses existed in all structures that failed. The low average net-stress fractures obtained in the tests described in the present paper under conditions not unlike those in actual structures, are sufficient proof that service fractures can and very likely often do start at low over-all stress levels.

The difficulty of initiation as compared to the case of propagation of fracture may be seen as a barrier: once this barrier is overcome, fracture may propagate easily. Fabrication and service conditions responsible for the lowering of this high initiation barrier are incompletely known. Thus, the existing theories can neither explain why brittle fracture had not been initiated at low static average stress nor indicate quantitatively the conditions which would make such initiation possible.

The difference between brittle initiations of fracture and those where general yielding first occurs can be explained easily in terms of the over-all stresses producing them.[1, 2, 11] In a symmetrically loaded plate subjected to central static loading, the roots of sharp notches yield at low nominal stress, but the strain in their vicinity remains quite small because it is contained by surrounding material stressed elastically (i.e., with small strains). The neighborhood of the roots develops large strains (more than a few percent) only when the whole section yields. Consequently, fractures which are brittle at the point of origin indicate an inability of the steel at the notch roots to withstand the small plastic deformation demanded from it at low average stress. Conversely, the fracture which initiates when the average stress level is low involves small plastic strains and is of the brittle type from the start. Thus, in an experiment, a low average net stress at fracture, although it is not the cause of fracture, is an obvious criterion for the brittleness of fracture initia-

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* The literature on the subject of brittle fracture is too numerous to be mentioned in detail. General presentations and discussions of the theories are given in references 1 and 2. Reference 3 discusses most of the work presented up to 1954.

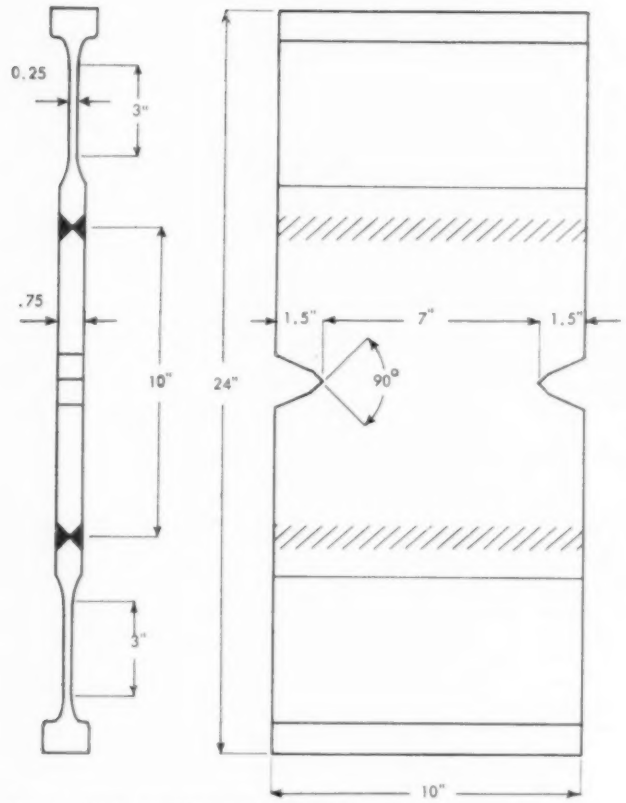

Fig. 1 10-in. test plate with plastic hinges

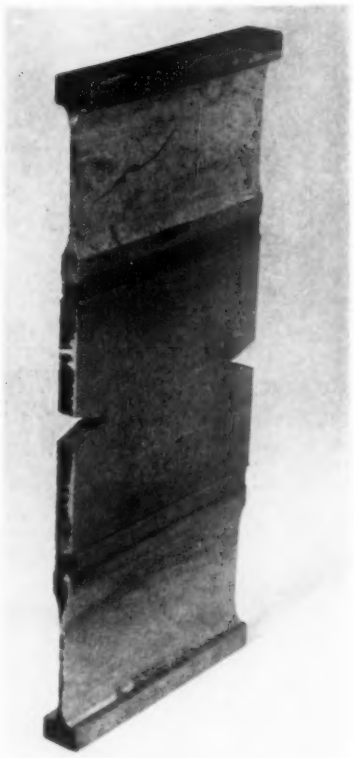

Fig. 2 Test plate showing plastic hinges

tion. Experiments where general yielding (i.e., net average stress of yield level) precedes fracture cannot help to explain or to understand the phenomenon of brittle-fracture initiation, because they do not correspond to the brittle in-service initiations of fracture they are supposed to simulate.

The object of the tests described in the present paper was to initiate fractures at low average static stress under controlled conditions and so permit study of the problem. According to the previous discussion, fracture initiation at low average static stress may be achieved with steel lacking the small amount of ductility required at the notch roots at low average stresses. But even poor but undamaged steels with the most severe stress raisers or constraints were found to exhibit sufficient ductility so as to break only at central static loads of yield level. It must be concluded that brittle-fracture initiation will be enhanced and the initiation barrier will be lowered under conditions which produce fracture at smaller strains, hence in general have the effect of a reduction or *"exhaustion" of ductility* in the region of fracture initiation.

Recent work of considerable importance has thrown new light on the problem of fracture. It shows the possibility that brittle-fracture initiation depends on the development of a critical stress several times larger than the static yield stress just below the root of a notch or crack, and that this may be achieved at very high stress rates in combination with low temperatures. This work is in full agreement with the opinion of the present and earlier papers,[1,2] that independently of the true cause of fracture, its "brittleness" or "ductility" can be judged by the average net stress criterion. However, this work does not seem to explain the cause of initiation of "brittle" fractures in plates under *static loading* and at moderately low temperatures, since even with the greater constraints of a round bar with a deep circumferential groove, fractures could not be produced at a temperature of $-110°$ F with rates of nominal net stress application lower than about 3×10^6 psi/sec, and at a temperature of $-25°$ F with even the highest applied stress rate of 1.5×10^7 psi/sec. To explain such fractures one must still consider conditions which will make possible the initiation of fracture at smaller overall strains.

The factors reducing the ductility have been extensively studied,[3,4] mainly by the amount they raise the empirical standard of brittle-transition temperature. None of them generally had been sufficient to initiate laboratory fractures at low net average stress, at least not when present in the amounts which are accepted as existing in actual structures and which have been found to raise the brittle-transition temperature well beyond the dangerous levels. Such factors are an originally high transition temperature of the virgin steel plate, welds, notches, sheared or punched edges,[17] prestrain and test temperatures below brittle transition. The effect of residual stresses is not certain, but as discussed later appears to be small. In particular, since no static test using undamaged steel had achieved low-stress fractures, it was felt that some factors acting during construction or service might produce sufficient additional embrittlement or reduction of ductility so as to permit low-stress fracture initiation. Welding, sheared edges, and the several possible types of prestraining were good possibilities. Prestraining seemed an important but insufficiently explored factor. It can greatly embrittle steel but follows unknown complicated path-dependent and temperature-dependent anisotropic laws of strain hardening. In the present tests, all these factors were used singly or in combination in an effort to achieve the

greatest exhaustion of ductility but, in general, without severely exceeding the conditions encountered in past or present construction practice or service. Once success was achieved, the conditions were changed to correspond better to possible conditions in actual structures.

Table 1—Composition and Properties of "E" Steel

C, %	0.29
Mn, %	0.39
P, %	0.017
S, %	0.035
Si, %	0.025
Lower yield point (according to parent plate), psi	33,000–30,000
Ultimate strength, psi	61,000
Elongation, over 2 in., %	36.5
Impact energy (Charpy V-notch), ft-lb	
−10° F	3
0° F	3.5
10° F	4.0
20° F	5.5
32° F	7.5

Description of the Tests

Steel

A $^3/_4$-in. pedigree rimmed project steel "E," of high brittle-transition range was used in all tests. Its typical composition and properties were as shown in Table 1.

The mechanical properties in the parallel and transverse directions to rolling did not differ significantly.

Plates with Compressive Prestrain

Most of the tests reported in this paper were made on $^3/_4$-in. thick, 10-in. square plates machine notched (except for the first 5 which were punch notched) on the sides parallel to the direction of rolling and welded to plastically yielding steel hinges for testing in tension (Figs. 1 and 2). Before welding, the notched plates were subjected to various amounts of prestrain in compression in the rolling direction. The compressive deformation was measured over a length 2 in. across the notch on the plate edge and over 1 in. at the notch root on the plate faces (Fig. 8). Buckling was prevented by two $1^1/_4$-in. thick plates supporting the compressed plate, one against each face. Friction was reduced by lubrication. Strain aging was minimized by keeping the plates at −25° F in a special freezer up to the time of testing, except for a period not exceeding a day needed for welding on the hinges and covering the test plate with 2-in. thick foam-plastic insulation. The test results of all plates with compressive prestrain are given in Table 2 (10-in. wide plates).

Testing

The insulated plates were taken directly from the freezer to the testing machine, and they were pulled some ten minutes later when the temperature had risen to about −5 to −10° F, which is below the lower end of the transition

Table 2 Brittle-Fracture Tests of 10-In. Wide Plates Prestrained in Compression after Notching

	Plate	Average compression* across notch (10^{-3} in.) 2 in. on edge	1 in. on face	Average net compressive stress, psi	Test temperature, ° F	Average net tension: Max. applied§ Psi	Max. applied§ % of virgin yield	At significant crack, % of virgin yield 1st	2nd	Obvious thumbnail
Punched	A10	None			−9	23,100	77			
	B10	None			−7	25,800	87			
	E10	30		34,800	−8	19,100	64			
	F10	40		36,800	−7	16,500	55			
	G10	40		35,700	−9	17,700	58			
Machined notches	H10	70, over 4″		36,000	−9	22,700	76			
	I10	Buckled		30,000	−7	>33,000	>110			
	J10	70, over 4″		36,400	−11	31,200	104			
	C10	None			−7	>33,000	>110			
	D10	None			−9	>33,000	>110			
	13A	50–67	31–35	35,600	−12	17,400	58			
	13B	61–50	33–34	36,500	−1	21,000	70	45		
	13C	11–8	15–13	31,600	−8	>32,100	>107			
	13D	24–6	19–9	34,800	−6	31,200	104			
	13E	38–27	22–17	36,100	−10	18,900	63	39†		
	13F	33–26	23–21	35,200	−10	17,400	58			
	13G	13–8	13–8	33,400	−8	>31,200	>104			
	13H	35–30	21–19	35,600	−9	26,400	88	38		$^3/_4$
	13I	51–44	17–17	35,600	−8	>31,200	>104	48		
	13J	40–38	14–13	35,400	−5	30,600	102			
	13K	35–36	9–11	35,400	−11	27,600	92			
	13L	35–33	11–9	35,400	−11	>31,200	>104			
	14A	30–26	19–19	35,600	−10	>31,200	>95	36		
	14B	30–36	20–20	35,600	−13	15,300	46			
	14C	28–26	21–21	36,200	−7	31,200	95			
	14D	27–29	22–21	36,200	−10	26,400	80	22†		$1^1/_4$
	14E	14–13	8–8	34,300	−10	>31,200	>95			
	14F	52–48	30–28	38,000	−4	30,300	92	15	29†	
	14G	33–34	19–20	35,200	−8	20,000	61	15	29†	$2^1/_2$
	14H	61–61	32–36	38,100	−4	12,000	36	14		
	14I	35–36	21–22	36,000	−2	27,900	85	14		1
	14J	52–50	32–34	38,100	−3	18,600	56	15		
	14K	Welded at notch roots			−11	>31,800	>96			
	14L				−10	>31,800	>96			
	14M	73–60	39–36	38,100	−9	14,400	44	12	39†	$3^1/_4$

Virgin yield 30,000 psi

33,000 psi

* First number for side of crack initiation.
† Louder noise.
§ Stress at fracture unless preceded by >, signifying that no fracture occurred.

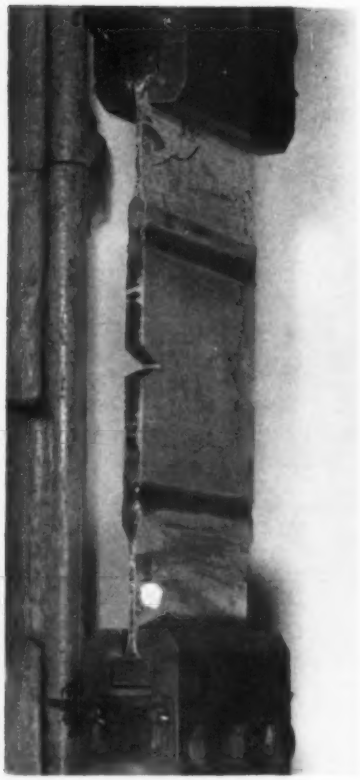

Fig. 3 Plate in testing machine showing plastic hinges and dovetailing T-heads

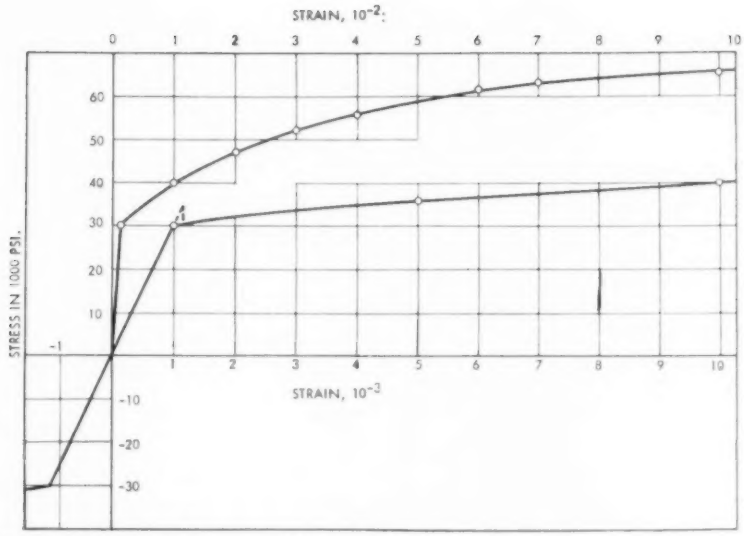

Fig. 4 Stress-strain diagram of hinge steel

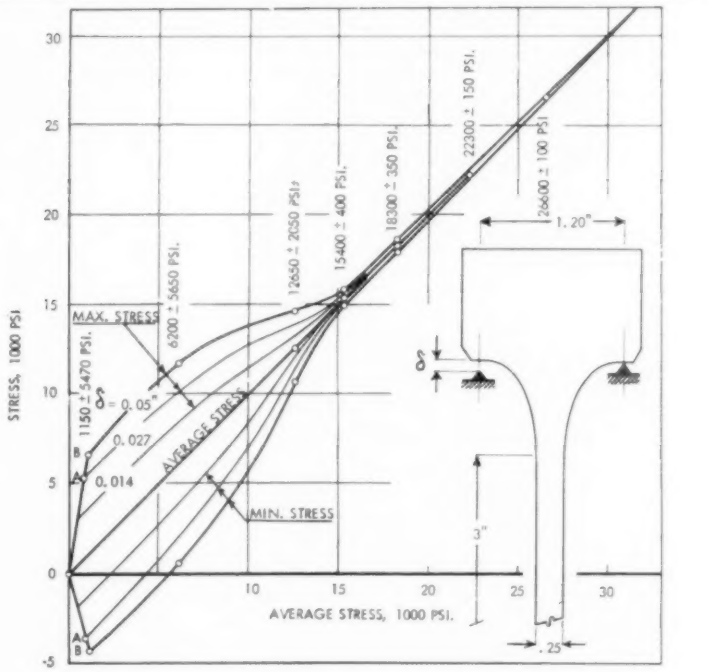

Fig. 5 Extreme vs. average stress in test plate showing the plastic hinge action

range (Table 1). The temperature was checked to differ by not more than 1° F over the significant test area. The loading was continuous at a speed of about 50,000 lb/minute, so that general yield was reached in about 3 minutes if the plate did not fail earlier.

Plastic Hinges

The T-heads of the plastic hinges dovetailed into special pulling heads (Fig. 3) which were held in the jaws of a 400,000-lb testing machine. The upper pulling head was put in place first, and the lower pulling head was clamped in the machine jaws as it was hanging in place from the test plate and upper pulling head. This helped minimize the in-plane eccentricity of loading. The out-of-plane eccentricity was reduced and gradually eliminated with increasing load by the yielding of the hinges. These were made of a steel (0.16–0.26 C; 0.60–1.00 Mn; max. 0.04 P; max 0.05 S; 0.15–0.30 Si; made to fine grain specifications), with a continuously sloping yield curve (no flat yield) and an ultimate strength about twice the lower yield point, so that the "hinge" worked over the greatest possible range of loads. The stress-strain curve is given in Fig. 4. The calculated effectiveness of the plastic hinges in centering the load is shown in the graphs (Fig. 5) of the extreme stresses over the net section of the test plate (without considering the stress concentration due to the notches) plotted against the average net stress. The graphs were calculated for the T-head initially touching on the one side (Fig. 5) and tilted so as to leave a gap of $^1/_{20}$ of an inch on the other side, which is several times more than actually observed. The calculations only involve the determination of the stresses in an eccentrically loaded wide beam subjected to prescribed strains and made of a material strain-hardening according to the curve of Fig. 4. The region OA corresponds to loads producing only elastic bending in the hinges; AB to plastic bending of the hinges up to the moment when both sides of the T-head are touching; and from B onward to increasing extension of the hinge without additional bending. It may be seen that the eccentricity existing at low loads is quickly wiped out as the hinges yield. At about 40% of average net yield the extreme stresses differ by

Table 3—Brittle-Fracture Tests of Plates Prestrained in Tension Transversely to the Direction of Testing

	Plate	Prestrain, %	Prestrain, direction relative to rolling	Temperature, °F	Max. applied net average tension, direction relative to rolling	Max. applied net average tension, Psi	Max. applied net average tension, % of Virgin yield	Type of notch	Impacts at fracture load	
Welded to pulling heads (W)	A2	2.4	∥	−9	⊥	33,000	103	Virgin yield 33,000psi	None	6-lb hammer blows at various loads
	B2	2.4	∥	−9	⊥	23,600	72		One	
	A3	2.6	∥	−11	⊥	31,900	97	Punched notches	None	
	B3			−3	⊥	34,100	103		One	
	C3			−3	⊥	32,000	97		Two	
	D3			−8	⊥	30,400	92		None	
Plastic hinges welded to pulling heads (HW)	A4	4.0	⊥	−12	∥	30,000	94	Virgin yield 32,000 psi	No hammer blows at any load	Cold worked at notch roots
	B4			−7	∥	30,000	94			
	C4			−8	∥	29,000	91			
	D4			−5	∥	>34,500	>108	Saw cuts		
	E4			−3	∥	>33,400	>104	Saw cuts		
HD	A5	6.0	⊥	−6	∥	29,700	93	Punched notches		
HD	B5			−8	∥	29,700	93			
HD	C5			−5	∥	22,400	70			
HD	D5			−6	∥	29,200	91			
HD	E5			−9	∥	25,700	80			
HW	A6	None		−7	∥	29,500	92			
HW	B6			−5	∥	29,100	91			
HW	E6			−7	⊥	27,600	86			
HW	F6			−8	⊥	30,500	95			
Plastic hinges dovetailing in pulling heads (HD)	G6			−4	⊥	33,600	105			
	C6			−9	∥	>37,000	>116	Machined		
	I6			−6	⊥	>32,000	>100	Machined		
	D6			−8	∥	>35,200	>110	Sawed		
	H6			−7	⊥	>32,000	>100	Saw cuts		
	A7	1.0	⊥		∥	29,000	91			
	B7				∥	24,200	76	Punched notches		
	C7				∥	27,600	86			

±16% (±6.4% of yield) from the average stress, and at about 50% of yield by ±2.5% (±1.25% of yield). When the initial tilt of the T-head is smaller, the stress differential practically vanishes at even smaller average stress. Curves are given for a mismatch δ of 0.05, 0.027 and 0.014 in.

Plates with Transverse Tensile Prestrain

An earlier series of tests, partially described in Reference 2, was extended and completed. It contains plates prestrained in tension as in Fig. 6a and then cut up in 10-in. squares, notched on the sides perpendicular to the direction of prestrain, and welded to pulling heads as in Fig. 6b so as to be tested transversely to the prestrain. Early in the series, plastic hinges were welded between plate and pulling heads, and later the hinges were made as in Figs. 1 and 2, dovetailing in the pulling heads. Some plates were prestrained in the direction of rolling, others at right angles to it.* The notches were punched, machined or sawed. In some of the tests, the plates were hit with a 6-lb hammer at various loads. However, this practice obscured the results of these tests without reducing the fracture load and was discontinued.

Standard tension specimens and Charpy V-notch specimens were made of plate material prestrained in tension. The tension tests showed[2] that the yield point is raised considerably in the direction of the prestrain, and that the yield strength is not lowered in the transverse direction. In fact, generally the 0.0005, 0.001 and 0.002 offset values are all equal or higher than virgin yield. The effect of prestrain on the Charpy V-notch brittle-transition temperature is shown in Fig. 7. The whole transition range is seen to be raised some 15° F by 1% prestrain and 25° F by 2% prestrain in tension. The direction of the specimen relative to the prestrain did not appear to be significant. These results agree with earlier tests on similar steels.[4]

Test Results

The results of the precompressed plates described in Section 2b are given in Table 2 and in the corresponding graphs of Fig. 8. As may be seen, the prestraining of notched plates in compression does embrittle them, since most fracture at an average stress over the net section considerably lower than virgin yield. Actually, failures have been recorded down to 36% of virgin yield. But even more than that, significant cracking noises have been heard much before complete fracture, at loads down to 12% of yield, and, in about half the cases, a thumbnail appeared on the fracture surface at depths between 1 and 3¼ in. from the notch root. Similar plate tests showed arrested cracks which developed at about 10 to 40% of virgin yield, but the plates themselves did not fail when loaded up to 90–95% of virgin yield. Thus, not only have brittle fractures been initiated at very low average net stress, but it is obvious that the cause of fracture lay in the prestrained region which was unable to yield by the small amount demanded by the elastically strained areas of relatively small stress surrounding the notch region. The concept of want or exhaustion of ductility is clearly exemplified. This is particularly well shown by the

* C. E. Turner of the Imperial College, London, pointed out a discrepancy in Reference 2 which led the authors to scrutinize the experimental data and to find that in Table 3 of that paper plates A-4 to D-6 should have been reported as prestrained in the direction of rolling and tested transversely to it. Plates A-2 to B-3 were correctly reported. The complete series of these tests, including the new results, is given in Table 3 of the present paper.

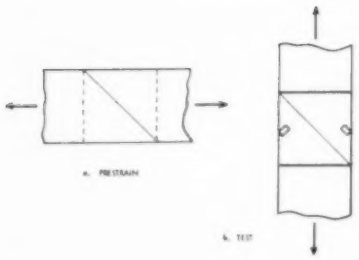

Fig. 6 Welded plates with prestrain transverse to the direction of testing

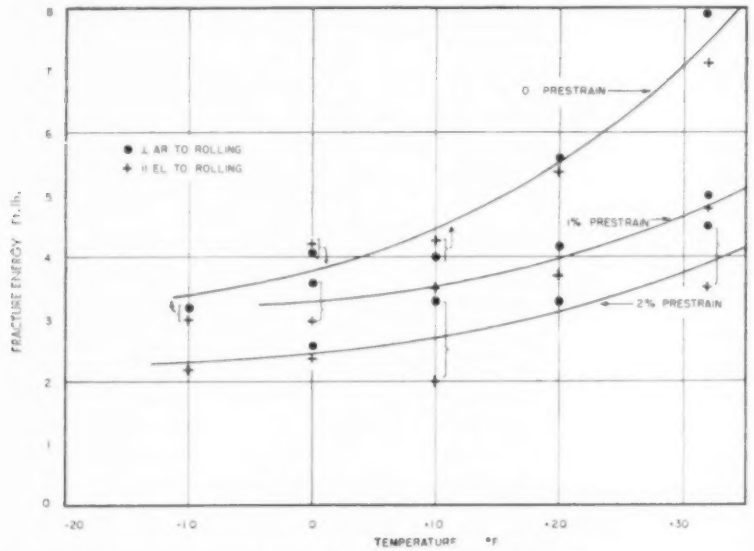

Fig. 7 Charpy-notch impact tests of steel prestrained in tension

cracks which were initiated at very low stress and were arrested at some distance from the highly prestrained tip, and by the inability of the remaining unstrained net section to fracture at loads producing general yielding. This low-stress fracture at a small depth of notch and the inability to fracture at high stress at the greater depth of notch plus arrested crack, and even more the arrest of a running crack of the highest possible sharpness at a length greater than when it started, raise serious questions as to the usefulness and perhaps even the applicability of energy theories of fracture in the problem of fracture initiation. It will be recalled that they predict an average fracture stress inversely proportional to the square root of the notch length.

The plates prestrained transversely to the direction of testing and then punch-notched failed systematically at average net stress below virgin yield but not as low as the precompressed plates. The lowest value was 70% of virgin yield (Fig. 9). The punching was chosen as a very severe punishment of the steel, known to induce fractures at average stress of yield level.[17] However, punching is not the sole cause of low-stress fractures. This is indicated by the plates with punched notches but no prestrain which always failed at higher average stress than the plates with prestrain. In addition, all the longitudinally prestrained plates described in Reference 2 failed well above virgin yield (but well below the raised yield) in spite of having punched notches. The influence of the combination of transverse prestrain and punching is clear.

Residual Stresses

The compressive prestrain of already notched plates produces yielding at the notch roots, and upon removal of the load obviously leaves the region of fracture initiation with appreciable residual stresses. These stresses are often considered to add to the externally applied stresses to produce early fracture. A discussion of their effect seems appropriate. Earlier investigators[3] have concluded that the residual stresses in the vicinity of a weld in a plate do not have a significant influence on brittle fracture, and also that they can be reduced considerably by low-temperature stress-relief procedures. However, other tests of wide plates of high transition-temperature steel with long welds and with notches made before welding and extending into the regions affected by the heat of welding, produced low-average-stress fractures, and even some spontaneous cracking over short distances beyond the notch roots.[8, 9, 10, 12] Several stress-relieving methods were recently tried on similar plates.[13] Low-temperature tests in tension parallel to the weld showed that the unrelieved plates fractured at low stress, but plates annealed above the transformation temperature, or stretched in the direction of the weld at a temperature above brittle transition, or (with slightly less success) plates stress relieved at low temperature, fractured only when the average net stress reached yield values. Since brittle fractures occurred in the presence of initial tensile stresses, but not after their removal, these tests were presented as proof of the importance of initial stresses in brittle fracture. However, earlier tests indicate that the conditions governing brittle fracture may be more complicated. Thus, tests[14] of a nature similar to those just described but with the notch made after welding did not lead to low-stress fractures, although the plates must have had high residual welding stresses, reaching and perhaps exceeding yield point at the notch roots. These tests were considered as proof of the unimportance of residual stresses in brittle fracture. The explanation of the low-stress fractures of the prenotched welded plates is that a very high straining[15] occurs at the roots of the notches during the cooling of the weld. In effect, the heat-affected zones without notches are strained by something of the order of 1%. In the presence of notches, extremely high local strains will occur and will exhaust the ductility at the most dangerous areas. On the contrary, the cooling of the unnotched weld area produces a uniform permanent strain but with residual stresses of yield level. Upon notching at room temperature, the plastic deformation of the notch roots will be much less than with prenotched plates, although residual stresses of yield level will remain at the notch area. The efficacy of the stress relief at a temperature above transformation is not surprising since it restores the ductility of prestrained steel. The results obtained by prestraining in tension at temperatures above transition indicate the importance of the strain history of the material. Similar results were obtained earlier by prestraining notched plates.[16] In the tests described in Reference 2 tensile prestrain was similarly found to increase the fracture stress even above general virgin yield, but not above the raised yield strength.

Since some amount of yielding usually precedes brittle fracture and, in essence, wipes out any pre-existing residual stresses, these cannot in general have an important influence in brittle fracture. Thus, one may assume a plate of those failing at low average stresses, say 50% of virgin yield, with high residual tensile stresses at the notches. At 30 or 40% of virgin yield the plate is still unbroken, but yielding has certainly occurred at the notch roots since the elastic factor of stress concentration is very high. If at this point the loading is stopped and reduced to a small value, the residual tension at the notch roots will be found to have disappeared and perhaps even be changed into a small amount of compression. If the unloading does not pro-

duce yielding in compression (and a load may be left on to ensure this), it does not in any way affect the plate which, upon reloading, should fail at the same low load as if the loading had been continuous. Yet, the plate of interrupted loading may be free of initial stresses or even have residual stress of reversed sign. The only effect of the initial residual tension is to increase slightly the plastic deformation preceding fracture at the root of the notch, but this strain must be a little larger yet still of the order of the elastic strain at the limit of elasticity. Usually, the plastic strains preceding brittle fracture are many times larger, so that the small importance of residual stresses is obvious. However, the residual stress may have an influence when the ductility at the notch roots is so highly exhausted and the material is so brittle that it cannot withstand plastic strains of the order of 0.001 in. Then even "spontaneous" fractures could be expected over regions with residual tension of yield intensity. This is what probably happened in the tests mentioned earlier. It is obvious, however, that the real cause of fracture is the very low steel ductility at the test temperature and not the residual stresses, since, even if free of residual stresses, these plates should have fractured at very low loads (such as the arrested cracks at about 10% of virgin yield mentioned in Paragraph 3). In fact, fracture should occur at an average stress which, multiplied by the very high elastic factor of stress concentration, would give yield stress at the notch. However, the visible signs of small amounts of plasticity in actual brittle failures seem to indicate that such high exhaustion of ductility is not usual. It thus appears that in the usual circumstances the residual stresses should be of small importance, but even when they have an influence this is only to hasten a fracture initiation which should anyway happen at a low load. The importance of the *small average net applied-stress criterion* of brittleness of fracture remains valid even in the presence of initial stresses.

Conclusion

Static initiation of brittle fracture at low average net stress requires a great reduction of the usual ductility of steel. The criterion of brittleness of fracture initiation, whether with or without residual stresses, is a low average net stress at fracture. Such exhaustion of ductility is easily achieved by compressive prestrain. In this way, typically brittle fractures have been achieved at static average net stress even smaller than 40% of virgin yield and arrested cracks at 10%. A discussion of the plastic strains at the notch roots shows that the residual stresses should not be of great importance. The strain history at the notches appears as a factor of great significance.

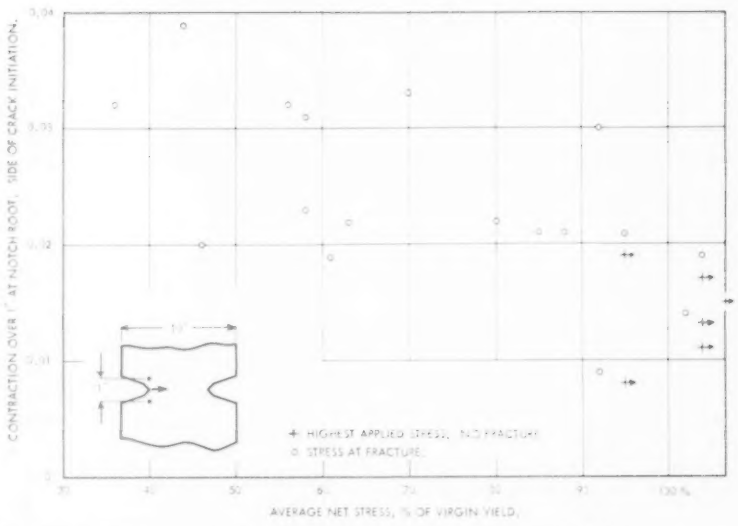

Fig. 8 Brittle-fracture results of longitudinally precompressed plates

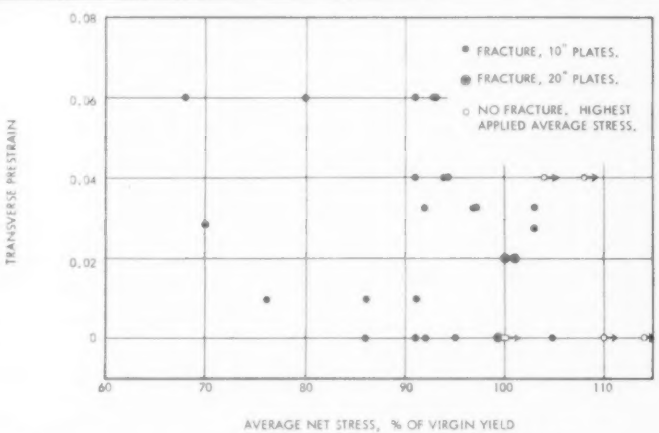

Fig. 9 Brittle-fracture results of transversely prestrained plates

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UNIVERSITY RESEARCH WORK

BY W. SPRARAGEN

Many years ago, under the old American Bureau of Welding, there was created a University Research Committee whose principal assignment was to stimulate research in welding and closely allied fields in the universities of the United States and Canada. Mr. Henry M. Hobart of the General Electric Co. was its first Chairman. In 1935 when the Welding Research Council was organized as the successor to the American Bureau of Welding, the AMERICAN WELDING SOCIETY requested the Council to take over the operations of the Structural Steel Research Committee and the University Research Committee. In other words, the activities of the University Research Committee antedate the work of the Council itself. The general objectives of the University Research Committee still remain the same, namely, the stimulation of research. However, to accomplish this objective the Council has developed a number of mechanisms, some of which are a continuation of the work of Mr. Hobart, and in other instances represent new ideas developed by the University Research Committee.

Perhaps one of the most outstanding activities of the Committee is a provision for an annual conference during the annual meetings of the AMERICAN WELDING SOCIETY. This conference is usually held on a Wednesday of the convention week. Over the years the character of these conferences has changed. They still manage to bring to the meetings of the AMERICAN WELDING SOCIETY at least thirty-five professors and instructors who are interested in research in welding and closely allied fields. As in the past, the Council makes provision for the payment of the travel expenses of any professor attending a conference with an upper limit of $50.00 to anyone present. During these conferences the university professors have an opportunity to exchange ideas between themselves. They have an opportunity to explain what they are working on, the difficulties encountered, the successes and the general objectives of the investigation. They have an opportunity to listen to outstanding papers presented during the convention week and to see the latest developments in welding equipment and apparatus. On some occasions keynote speakers at the University Research Conference have provided inspiration and suggestions for new research work which might be undertaken.

About once in two years the Welding Research Council compiles a list of welding research problems which Industry would like to have solved. These problems are usually subdivided into general fields of applications or branches of engineering and science. The list is published in the *Welding Research Supplement*. Reprints are made available to the deans of engineering and heads of engineering departments of every major university in the United States. The preamble to this list of problems indicates that the Council is willing to assist in the formulation of any problem selected by a specific university. In some specific instances grants-in-aid have been given or special test specimens have been prepared.

A relatively new activity of the University Research Council has been the compilation of a University Research Directory. In this Directory there is included all of the universities interested in welding research or research in closely allied fields. The problems on which the universities are working are listed, as well as the professors and investigators in charge. Another section includes brief biographies of all the university research professors and instructors interested in research work in this field. Another section includes special apparatus or facilities available at specific universities. The intent of the Directory is to make available in readily usable form information about the major universities so that corporations, trade associations or governmental departments wishing to place research projects at some specific university can do so without going through the Welding Research Council as an intermediary. It is expected that this Directory will be kept up to date and revised at suitable intervals.

A relatively old mechanism for the stimulation of research in the universities is a provision for occasional visits to the universities by staff members of the Council or by important members of the University Research Committee. In the past these visits have been responsible for getting several universities interested in undertaking researches in the welding field and plans are under way for reviving these visits.

At the most recent Welding Research Conference held in St. Louis in the spring, a suggestion was made that the Council undertake the preparation of a new list of problems. This new list would include problems which the universities would like to work on if funds and support were made available to them for conducting investigations in these fields. It is hoped that this new venture will be equally successful.

Mention has been made above of grants-in-aid given by the University Research Committee. The Welding Research Council makes available to the University Research Committee the sum of $5000 each year for these grants-in-aid. The University Research Committee has limited the amount to any one individual to $2500 a year. There is a time limit of two successive years in which the Council will support a specific investigation. The rules provide that research problems must be of a fundamental or a basic nature. If a suggested problem on which support is desired lies within the field of one of the Project Committees of the Council, the problem is referred to that specific Project Committee.

In other words, the University Research Committee wishes to confine its support to fundamental and basic problems for which no other support is in sight at the moment.

W. Spraragen is Director of Welding Research Council.

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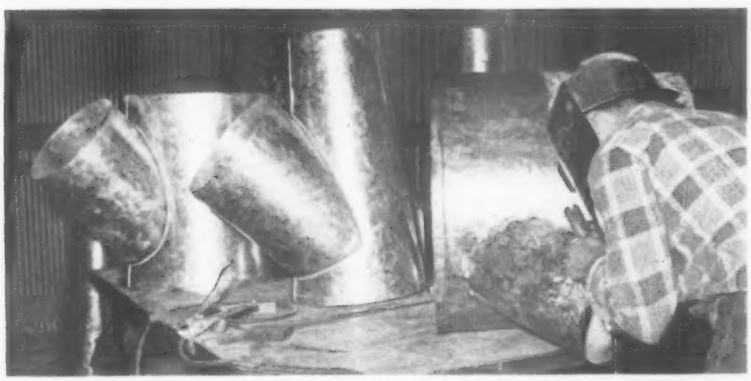

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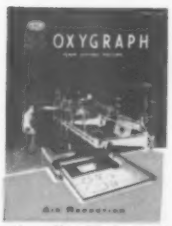

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